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Field comparison of traditional and slow releasing nitrogen fertilizers

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Field comparison of traditional and slow releasing nitrogen fertilizers

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This is to certify that the master's thesis of

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has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

In memory of those who have shared in my life,
but cannot see me today.

In appreciation of those who are in my life,
and have helped me find tomorrow.

To Kari, and to my family:

In order to have dreamers
there must be believers.
Thank you for believing,
and supporting me along the way.

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ABSTRACT

Slow release fertilizers are a possible alternative to traditional fertilizers. With growing environmental concerns slow release fertilizers are a potentially more efficient method of delivering nitrogen (N) fertilization. Slow release fertilizers have been used for high-value crops, but, only recently, new formulations have been produced and are being re-introduced into row crop production. A two-year field trial was conducted to assess the effect of a urea-formaldehyde (Nitamin) slow release fertilizer on grain and biomass yields, and the corresponding amounts of N uptake, in corn in 2004 and 2005. To accomplish this, fertilizer rates of 0, 56, 112, 168, and 224 kg N ha^{-1} were used of both Nitamin and urea ammonium nitrate (UAN) fertilizer materials. The results obtained showed great variation between the two years of the study. In 2005 there was a significant increase in grain production when Nitamin was used as an N source. There was also a statistically significant increase in N uptake in Nitamin treated plots and a trend toward higher biomass production and N uptake in biomass in urea-formaldehyde treatments. In 2004 grain production was affected by N rate with trends favoring UAN fertilization. When all experimental data were analyzed there was a significant increase in grain production in plots receiving Nitamin fertilizer treatment.

CHAPTER 1.

INTRODUCTION

Although nitrogen gas (N_2) makes up approximately 78% of the extant atmosphere, it is often the most limiting element for plant growth. After carbon, hydrogen, and oxygen, nitrogen (N) is the most abundant element in living tissues. N is a structural component of DNA and RNA (nitrogenous bases), amino acids (enzymes and precursors of protein), and amino-sugars (chitin) (Sprent, 1987). With the broad range of functions performed by N within plants it is clear that a deficiency can be detrimental to growth and reproduction. Due to this importance, it is also probable that any practice leading to a greater level of N taken up by plants could lead to an increase in the production of biomass and grain.

Plants predominantly take up N in its inorganic forms, generally as nitrate (NO_3^-) or ammonium (NH_4^+). The challenge occurs in that the forms of N present in soils are readily altered by changes in the physical and chemical environments. These inorganic forms of N make up a small percentage of total N in soil, organic forms of N make up 90% of soil N (Stevenson, 1982). The organic portion of soil N is represented by microbial biomass, plant tissues, and living organisms ranging from alive through a progression of stages of decomposition. The inorganic forms of N, nitrate-N (NO_3-N) and ammonium-N (NH_4-N) as discussed here, are either very mobile or immobile in soil. Ammonium-N has a +1 electrical charge, due to this and it's relatively small hydrated ion radius, NH_4-N is retained by the cation exchange of layer silicate clays and soil organic matter. Although NH_4-N is not readily leached it is vulnerable to volatilization, conversion to ammonia gas (NH_3), and fixation, the trapping of NH_4-N in the interlayer of 2:1 clays. Finally, ammonium-N can be nitrified, oxidized to nitrate-N, by a series of biological oxidations, by *Nitrosomonas ssp.* and *Nitrobacter ssp.* Nitrate-N, having a negative charge (-1), is both soluble in water and repelled by the cation exchange, which also has a negative charge. If not taken up by plants nitrate-N has the potential to leach downward, out of the plant root zone and into the ground water. Nitrate-N may also be lost to the atmosphere by denitrification, reduction of nitrate to a gaseous form. Both of these forms of N may also be made unavailable by incorporation into microbial biomass, immobilization.

Nitrogen loss from soils, especially through leaching, has caused great concern in recent years over lost investment by agricultural producers, and detrimental effects to human health and the environment. Nitrogen that is not utilized by plant or microbial life can be lost from the soil profile, some estimate that more than 20% of N applied in the Mississippi River Basin ends up in the Mississippi River and eventually the Gulf of Mexico. This nutrient enrichment has the potential to cause a reduction in the amount of dissolved oxygen in the water, which can create a hazard to aquatic life.

Recent research has shown that the availability of N at certain critical times in the life cycle of corn has the ability to increase grain yield. This has led growers to explore different methods of fertilization to maximize utilization of N by crop species and in doing so decrease the amount of N lost to the environment.

Nitamin, a urea-formaldehyde (U-F) based N fertilizer, a product of Georgia-Pacific Resins, Inc., a Koch company, is designed to prevent the loss of N by reducing the rate at which the fertilizer becomes soluble. Ideally, if the fertilizer releases its N at the rate the plant needs fertilization there could be 100% utilization of the fertilizer, by plants and microbes, and 0% loss. The mechanism for release of N from Nitamin is a variance of the length of U-F polymers. Shorter chains release their entire N content more quickly and longer chains more slowly. These polymers are broken down, which releases N, by microbial activity. Nitamin is available in several forms including: impregnated in expanded vermiculite, as a coating on sand, and liquid. The liquid form was used in this research study.

The objective of this study is to evaluate the use of Nitamin as a N fertilizer for corn production compared to urea ammonium nitrate as an N source.

General Literature Review

General Nitrogen Information

Nitrogen is often the most the most limiting nutrient for crop growth (Lohry, 1995). This is of concern as N is the fourth most abundant element in organic tissues, after carbon, hydrogen, and oxygen. Nitrogen, as dinitrogen gas, makes up approximately 78% of our atmosphere, but plants cannot use it in this form due to the energy required to break the very stable inter-atomic bonds (Sprent, 1987), and therefore rely on fertilizer application, or activity of microorganisms, through mineralization and nitrification, to supply the N needed to avoid deficiency and potential loss of yield. Approximately 37% of all organic N and 22% of inorganic N is found in terrestrial environments (Sprent, 1987). Plants predominantly take up N in the inorganic forms of nitrate (NO_3^-) ammonium (NH_4^+), although predominantly as NO_3^-, In most soils 90% of the N is present in organic forms (Stevenson, 1982), leaving a relatively small portion of soil N in the inorganic forms (up to 5% of total soil N) (Smith, 1982). Thus it is possible to have soils high in total N, but very low in available N. Organic reduced N occurs in many forms including urea, nitrogenous bases (DNA and RNA), amino acids and their compounds (proteins and enzymes), and polymers of amino sugars (chitin of insect exoskeletons). The inorganic portion of soil N is significantly greater in agricultural soils (Sprent, 1987).

Nitrogen fertilizer is used in incredible quantities by the agricultural sector in the United States, from 1959 to 2001 there has been in average annual increase

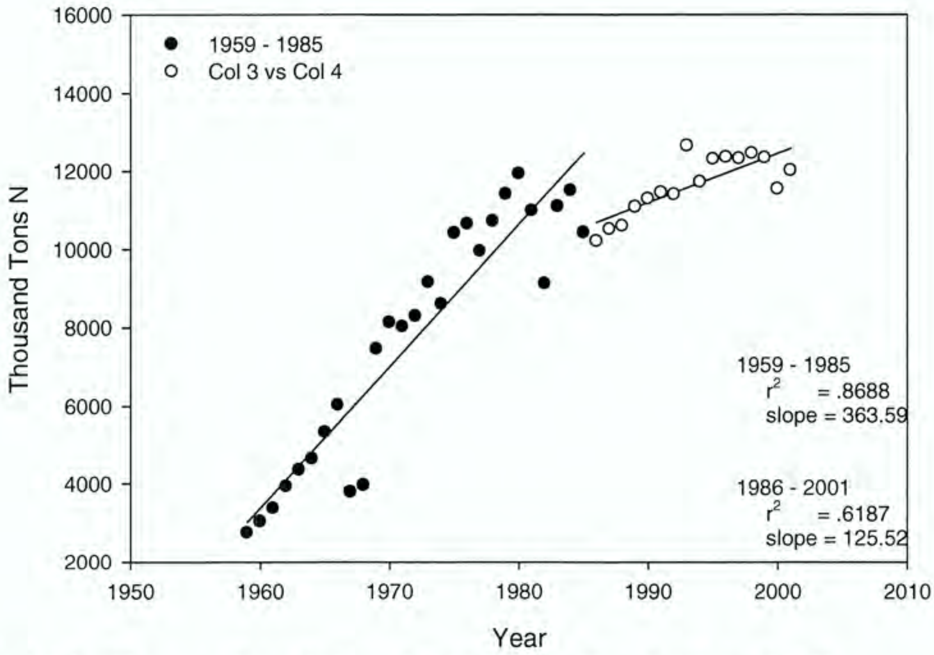

Figure 1.1. US fertilizer use from 1959 to 2001 (The Fertilizer Institute, 2006)

of 223.4 thousand tons. There was a much greater annual increase from 1959 through 1985 an average annual increase of 363.6 thousand tons. This represents an increase from 2,738 thousand tons in 1959 to over 12,300 thousand tons in the late 1990's (The Fertilizer Institute, 2006), over a 450% increase in N fertilizer use.

Iowa has slightly over 14.5 million ha of land area, 89% of which is part of farming operations (State of Iowa, 2006). From 1991 to 2003 an average of 37% of all hectares in the state have been used for corn production, and these numbers are increasing. There have been over 4,049 (0.03%) additional hectares used and 5.4 million kg of N applied each year during this time period (NASS, 2006).

Plants predominantly take up N in the form of NO_3^-, which is then reduced, by the enzyme nitrate reductase, to NH_4^+. This reduction can take place in any organ of higher plants (Andrews, 1986; Wallace, 1986). The preference for uptake of nitrate-N over ammonium-N, even though this pathway requires an extra step in converting between forms of nitrogen, is thought to be due to the toxicity of ammonium at all but low concentrations. Ammonium is then assimilated into plant tissue by two main pathways, GS:GOGAT system, the mechanism of ammonia assimilation in plants, (Sprent, 1987).

Nitrate is the most mobile form of nitrogen in most soils, and under certain conditions NO_3^- can be leached from soil profiles. In soils with cation exchange, and soluble forms of nitrogen, nitrate-N, the rate of downward movement of nitrate is affected by the water content, fertilizer application rate (Bergstrom and Brink, 1986), and soil texture (Kolenbrander, 1981) among other factors. In some systems these losses are found to be in the range of 40 to 70% of the applied fertilizer (Lohry, 1995). In addition to potential degradation to the environment and loss of yield, nitrate is also potentially toxic to humans with a potential of causing methemoglobinemia, the presence of methemoglobin in the blood caused by conversion of hemoglobin by nitrite (Merriam-Webster, 2002). The gastric systems of infants do not have the proper contents to prevent the reduction of NO_3^- to NO_2^-. Current EPA standards do not allow for NO_3-N to exceed 10 ppm in drinking water (EPA, 2004). These findings have been disputed by some stating there is no medical evidence for a maximum allowable level of NO_3^- in drinking water of less than 100 pm (Owen & Jürgens-cschwind, 1985)

Ammonia can be released into soils by nitrogen fixation or through the decomposition of soil organic matter, both by microorganisms and free enzymes. Outputs of N increase as soils are disturbed through cultivation compared to undisturbed systems.

Fraps (1908, 1912) showed that average nitrogen content of crops increased with amount of nitrate formed in the soils, and that the effect of added nitrogen fertilizer is negatively correlated with the amount of nitrogen produced by the soil. Similarly it has been reported that nitrogen uptake is linearly related to nitrogen application rate, in millet (Stanford and Hanway, 1954). Andharia (1952) found highly significant correlations between the yield of corn and the quantity of nitrate nitrogen released over various periods of incubation.

Nitrification, the biological oxidation of ammonia, is mainly carried out by two species of bacteria, *Nitrosonomas ssp.* and *Nitrobacter ssp.*, through two steps, ammonia (NH_3) → nitrite (NO_2) → nitrate (NO_3), under aerobic conditions. This process has a pH optimum of 7-8, as *Nitrobacter ssp.* is very sensitive to pH, largely because free ammonia and nitrous acid are both very toxic to it. *Nitrosomonas ssp.* is slightly less sensitive to these chemicals (Sprent, 1987).

Mineralization is the process by which organic compounds in the soil decompose to release ammonium ions with concurrent release of carbon (CO_2). The extent and rate are affected by decomposing substrate, soil temperature, soil moisture (with rates increasing up to field capacity), and pH (liming up to 6.7 is known to increase mineralization rates). Agricultural practices involving cultivation usually enhance mineralization due to increased aeration, but this increase also diminishes the total organic N content of the soil.

Immobilization is the net incorporation of mineral N, usually ammonium, into microbial biomass (Vinten & Smith, 1993). This is largely influenced by the ratio of carbon to nitrogen in the soil, a low C:N ratio results in net mineralization and a high C:N ratio results in net immobilization.

Denitrification is the complete reduction of $2NO_3^-$ to N_2 (disimillatory nitrate reduction). Optimum conditions for this process are 25 °C and above, pH of 7-8 (Fillery, 1983), and an anaerobic environment, although denitrification can occur in almost all known environments due to anaerobic microsites in soils, and as such, rates of denitrification are correlated with water content. Nitrite may also be denitrified, but it is not thought to contribute significantly to total denitrification because soil nitrite levels are generally low (Vinten and Smith, 1993).

Volatilization of ammonia is markedly effected by soil pH. Soil pH values above 7.0 increase volatilization, and the effects are more pronounced at high temperatures and wind velocities. Volatilization is also affected by buffering capacity (higher capacity generally corresponds to greater loss) and cation exchange capacity (higher capacity generally corresponds to decreased loss).

Environmental Effects of Nitrogen

Under ideal moisture and temperature conditions, added fertilizer N in any form is converted to NO_3-N, which is the primary form used by plants. Nitrate is completely soluble and mobile in and with water. When present at levels in excess of plant uptake NO_3-N may leach into the ground water (Linville and Smith, 1971), if the soil has good permeability, they indicate that soil texture may have an effect on depth of nitrate-N accumulation and other studies have suggested that depth of accumulation may also be a function of application rate of N fertilizer. The moisture status of soils is also one of the most important factors controlling nitrogen transformations, allowing for production of oxidized or reduced forms of N in aerated and saturated soils, respectively. The range of soil moisture between field capacity and wilting point is favorable for nitrification. Miller and Johnson (1964) reported that maximum nitrification occurred at a moisture tension of 0.50 to 0.15 bars during incubation of four soils. Sabey and Johnson (1971) found that the NO_3-N accumulation rates were greatest at 0.05 and 0.1 bars, and at 0.33, 0.5, 1, 5, and 15 bars, NO_3-N accumulation rates were 63, 51, 40, 10, and 14%, respectively, of the rates of 0.05 and 0.1 bars. They reported that there was very little accumulation of NO_3-N in saturated soil. Reichman et al. (1966) found that mineralization and nitrification of soil N in samples of a Chestnut and a Chernozem soil were almost directly proportional to soil water content at suctions between 0.2 and 0.15 bars. Prasad and Rajale (1972) found that urea was mineralized and fairly well conserved at field capacity or under continuous flooding but was rapidly lost under alternate flooding and drying. This loss of urea was potentially caused by nitrification.

The extent of nitrate movement through the soil profile is directly related to the amount of water applied at one time. Shaw (1962) reported that about 30 cm of rain was required to remove an application of 134 kg NO_3-N ha^{-1} from the surface 15 cm of a sandy soil. He found that an additional 20 cm of rain removed 40% of the added nitrate down to 30 to 45 cm layer. While Corey et al. (1967) indicated that in unsaturated flow conditions there was a net gain in nitrate.

Adriano et al. (1972) found that the NO_3-N concentration in the unsaturated zone of an alluvial soil increased with an increase in N rates, but was inversely related to the leaching volume. They assumed that denitrification was the cause of the high N losses with high irrigation, and it was reported that N losses through denitrification, plus net N immobilization, ranged from 18.3 to 67.7% of the applied N. Meek et al. (1969) increased the water content of a soil having a water saturation percentage of 41% to 44.5% or above and noticed large losses of N_2 gas both with and without addition of organic matter, and Linville and Smith (1971) state that losses by leaching and/or denitrification from a loam soil profile appeared to have been substantial regardless of the amount of N applied.

Most of the annual nitrogen input, 40 – 70%, is removed in the harvested crop, or lost through denitrification, volatilization, and soil immobilization. Nitrogen not consumed by these methods is subject to leaching, primarily due to seasonal precipitation. Linville and Smith (1971) found no evidence of NO_3-N movement beyond a depth of 224 cm (8 ft) in Missouri soils when ammonium nitrate was applied to continuous corn plots at rates of 124 and 134 kg N ha^{-1} annually for 6 and 7 years on 4 soil types and for 20 years on one soil type. Three cm of water on silt loam or clay loam can move nitrate-N down 10 to 15 cm, and up to 30 cm in sandy soils. Owens (1960) reported that over a period of 2 years, corn crops recovered 15 to 24% of the applied N. Lunt (1971) found that a corn crop recovered 71% of the N applied as urea when the soil received 56 cm of water, but only recovered 47% when the soil received 102 cm of water. Nitrate concentrations in agricultural drain water can be very high, 20 to 40 mg L^{-1} or more (Zucker and Brown 1998), and 8 to 38 kg ha^{-1} in research plots depending on application rate and timing in parts of the upper Mississippi River basin (Potash & Phosphate Institute, 1999). Using ^{15}N, Kohl et al. (1971) found that at the time of high NO_3-N concentration in tile drainage water in the spring, 55 to 60% of the N in the field tile drain water had originated from fertilizers. Erickson and Ellis (1971) reported that 20% of the 39 kg N ha^{-1} applied on a clay loam soil under sugar beets and beans was lost in drainage water. Additionally it is estimated that, without best management practices, 12% of applied N may be lost as surface runoff. Minshall et al. (1969) found that in southwestern Wisconsin the total annual N in the base flow was ¼ of that lost in the surface runoff, and that method of incorporation, runoff volume, and timing of runoff relative to date of application had a greater influence of loss of NO_3-N to surface runoff than did application rate (USDA-ARS and the University of Missouri as reported in Potash & Phosphate Institute, 1999). As might be expected, the higher N yields in streams

(1,001 – 3,050 kg km^{2-1} yr^{-1}) are from basins where the N inputs are higher. These basins also tend to be in areas of the Mississippi basin where precipitation is high and subsurface drainage is used extensively (Goolsby and Battaglin, 2000). Actual amounts of N inputs into streams may be larger than those reported by water testing due to denitrification in all phases of transport. Lunt (1971) stated that although denitrification generally keeps nitrate concentrations of streams at low levels, some studies show 50% or more of applied fertilizer N was in the drainage water.

Eutrophication is the process of enriching water with dissolved nutrients, especially nitrate and phosphate. This process can lead to hypoxia, which has been operationally defined as that condition in which dissolved oxygen concentrations are less than 2 parts per million of water (Potash & Phosphate Institute, 1999). Hypoxia has been documented on the Louisiana shelf since the 1970s. Some Marine scientists have suggested that the principal cause of the hypoxic zone in the Gulf of Mexico is NO_3-N discharge from the Mississippi River. Some estimates suggest that approximately 89% of the annual total nitrogen flux comes from non-point sources (Goolsby and Battaglin, 2000). These scientists have reported a strong correlation between long-term (1930s to 1988) annual fertilizer N consumption and NO_3-N concentration in the lower Mississippi River, although this strong relationship does not mean there is a cause and effect relationship between U.S. fertilizer N consumption and the total quantity of nitrate-N delivered to the Gulf. Neither is there a significant relationship between N fertilizer consumption and the size of the hypoxic zone measured since 1985 (Potash & Phosphate Institute, 1999). Evidence of anthropogenic change in the Mississippi River watershed also exists, which may affect the processing and delivery of nutrients to the northern Gulf of Mexico. Anthropogenic changes made to the watershed include modifications, which have changed the flow of water in the Mississippi river significantly over the past 100 or more years. Many of these changes have been a result of attempts to maintain navigation and reduce flooding along the river. These alterations, by themselves, probably have had an important influence on the way in which solutes and particles have been transferred and processed in the river.

The Mississippi River and its distributary, the Atchafalaya River, drain about 41% of the conterminous United States. This area contains about 80% of corn and soybean hectares, and 58% of all cropland (Potash & Phosphate Institute, 1999). Approximately 11.6 million metric tons of N are added to the Mississippi River basin annually, excluding oxidized soil organic N, and 51% is added as commercial fertilizer N (5.9 million metric tons). Since 1980, 1.5 million tons (13% of total N applied) per year escapes to the Mississippi River and the Gulf of Mexico. Nitrogen, particularly nitrate (Goolsby et. al., 1997), has been implicated as one of the principal causes for the expanding hypoxic zone that develops each spring and summer on the Louisiana-Texas shelf of the Gulf of Mexico (Goolsby and Battaglin, 2000). Nitrate transport to the Gulf has not increased appreciably since the early 1980's, however the year-to-year variability has become large, due to changes in river flow. Russell (1972) states that the technical difficulties in determining the fate of the added N are, first, that it is not usually possible to determine either the amount of NO_3^- being leached out of the soil or the amount that is denitrified in normal field soils. Second, only a part of the NO_3-N present in the soil is derived from the fertilizer. In some systems a large portion has been derived from the decomposition of the soil organic matter., Russell indicates that it is not yet possible to prove conclusively what proportions of the nitrate in streams draining out of well-farmed land have been derived from N fertilizes added to the soil.

Effects of Climate on Plant Growth

Climate has a marked effect on the amount of nitrogen that is accumulated in the soil. Rainfall and temperature conditions determine the amount of organic matter accumulated in the soil. Sievers and Holtz (1923) reported that nitrogen content was four times as high in soil under 51 cm of annual rainfall than that under 20 cm per year. Greaves and Carter (1920) observed that ammonification and nitrification rates reached a maximum when the moisture content was at 60% of water holding capacity, while Jenny (1928) illustrated that mean annual temperature was inversely related to nitrogen content in the soil. The microbial decomposition of organic matter was given as the explanation for the loss of nitrogen from the soil. According to Jenny (1928), N content of a soil is higher under cooler conditions, which agrees with Hagan (1952) who indicated that many investigators have observed reduced nutrient uptake at low temperature, although it is difficult to determine whether this is conditioned by the indirect effect of reduced metabolic activity (Hoagland and Broyer, 1936). However, Hagan added that there is evidence to indicate that low temperatures do not appear to seriously retard nitrogen absorption; but they do affect the assimilation and translocation processes. Another possible explanation for the differences of nutrient uptake at varying temperatures and moisture contents is that both of these factors contribute to the level of transpiration in a plant, as these factors affect transpirational flow.

In corn the greatest yield reduction occurs when the plant is under stress during tasseling-silking or pollination. Water stress has the greatest impact on the particular organ being developed when the stress occurred. Miller and Duley (1925) obtained a 43% yield reduction by imposing a water stress of 30 days beginning at early tasseling. Robin and Domingo (1953) found that water deficits for periods of one to two days during tasseling resulted in a 22% yield reduction while six to eight days of wilt during the same period caused yield reduction about 50 percent. Loomis (1937) and Hanway and Englehorn (1958) reported that drought-injured corn contained higher total nitrogen in the leaves and stalks than did normal growing plants, as drought can cause incomplete pollination providing less reproductive tissue to accumulate nitrogen (Brunson and Latshaw, 1934).

The plant is considered under stress when the soil moisture cannot meet the atmospheric demand for water. Dale (1964) defined a stress day as any day in which the combination of evapotranspiration demand and available soil moisture did not permit the potential water loss to occur. Corsi and Shaw (1971) evaluated several stress indices and found two which best explained variations in corn yield due to moisture stress, Indices II and III. Index II, Turgor loss index, is a relationship between soil moisture and evapotranspiration, and Index III is a relationship between potential and actual evapotranspiration, as affected by soil moisture. It was also observed that plants may wilt under conditions of adequate soil moisture with low soil temperature when transpiration was sufficiently rapid.

Nitrogen Requirements of Corn

The amount of N fertilizer needed for profitable yields of corn depends on the desired yield level of the crop, the amount of release of N from organic matter, and the efficiency of usage of the applied N. The N requirements of corn are large and few soils can supply adequate amounts without fertilization. Investigations show that the amounts of nutrients found in the plant depend upon many factors including: variety, developmental stage, condition and characteristics of the soil, climate, and cultural practices among other possible factors.

A group of workers, Jones and Huston (1914), Radu (1937), and Sayre (1948), found that the pattern of nitrogen accumulation in the whole corn plant parallels, or slightly precedes, the pattern of dry matter production until sometime following tasseling and silking. Sayre, for example, reported that one-month-old plants contained about 3.9 kg N ha^{-1}. Ten days later when the dry matter production was increasing rapidly, the plants had accumulated 17 kg N ha^{-1}. At about silking time, during the most rapid period of dry matter production, the plants were accumulating 4.5 kg N ha^{-1} day^{-1}. Following tasseling and silking the pattern of N uptake was not clear-cut and apparently depended upon the N supply available in the soil and upon other factors affecting absorption.

When stalks begin to elongate the plants have accumulated 6% of their total dry weight and 10% of their total N uptake. By silking (approximately a month later) the dry weight and N uptake had increased to 44% and 50%, of its total, respectively. At this point the plants have a relatively high proportion of their N in the leaves, approximately 30% of total plant N in only 13% of total dry matter (Hanway, 1962), which by this stage have nearly completed their growth. Sayre noted that N accumulation in the whole plant, after reaching a peak about silking time, continued for another four weeks and then stopped somewhat abruptly. Jones and Huston observed that the silking peak was followed by a decreased rate which again became high at about the time the kernels began to glaze. Whitehead et al. (1948), and Jordan et al. (1950) all observed accumulation until maturity. Glover (1953), using sand cultures, found N absorption decreased during the setting and ripening of the grain, quickly falling off to a very low level before harvest. When the plant reaches maturity the grain contained 62 to 70% of the total N, of which approximately 50% appeared to have been translocated from other above-ground plant parts. Nitrogen accumulates rather rapidly in the grain until maturity. This is accomplished in large part through movement and depletion from other plant parts (Jones and Huston, 1914; Sayre, 1948; and Jordan et al., 1950). In addition some N may have been lost during the reproductive portion of the plant life cycle through pollen shed and transpiration.

The accumulation of dry matter in the corn plant tends to follow the characteristic sigmoid-shaped curve (Bair, 1942). Miller (1943), in Kansas, noted, during the first week following emergence, that leaves accounted for almost 100% of the dry matter of the plant. During the second week, the stem began to contribute a larger proportion of the weight, and between the eighth and ninth weeks, the stem and the leaves comprised an equal portion of the total dry weight. During the next five weeks, the dry weights of the stems increased rapidly, much faster than the leaves, Kiesselbach (1950) found that leaf area increased in a sigmoid-shaped curve from emergence until about silking, after which leaf growth stopped abruptly. Weihing (1935) observed that the full number of functional roots were also attained by tasseling, however, the length and depth of penetration of the main roots increased to maturity. Sayre (1948) in Ohio found the maximum rate of dry matter production during which time tasseling and silking took place, and increase in height had ceased. At tasseling and silking, approximately one-half of the final dry weight of the plant had been produced, and dry matter accumulation drops off rapidly as maturity is approached. At maturity the grain accounts for about 45% of the total dry weight Hanway (1962a)

Evaluation of Nitrogen Level

Both late spring soil NO_3^- concentrations and stalk NO_3^- concentrations are good indicators of nitrogen sufficiency, but early season rainfall (March – May) is the greatest determining factor for N availability for corn as it approaches its rapid growth stage starting in early June (V6). Regression analysis showed that annual means for concentrations of soil and stalk NO_3^- decreased with increased annual rainfall, it explained 74% of the variability in annual means of soil NO_3^- concentrations between the fields studied (Balkom, 2000).

Anhydrous ammonia accounts for the highest percentage of fertilizer sales, on a tonnage basis, in the West North Central states (Berry, 1992). Fall applications of anhydrous ammonia offer advantages to farmers and dealers (Stehouwer and Johnson, 1990; Bundy, 1986). These advantages include less time constraints associated with application and alleviation of supply and demand conflicts.

However, potential losses of NO_3^- associated with denitrification and leaching are greater compared to spring applications, especially in years with above average moisture and temperatures in the late Fall and Winter months, and to an even greater extent compared to side dress applications (Stehouwer and Johnson, 1990; Bundy et al., 1992; Fox et al., 1986). Timing N applications to coincide with periods of rapid uptake decreases the risk associated with leaching and denitrification because plants can utilize applied N more efficiently before substantial losses occur (Olson and Kurtz, 1982). Application of additional N (late May to Mid June) significantly increased yields at two, and grain protein in all, of the sites in one experiment, and in 31 of the 33 experiments conducted from 1946 to 1956, as a side dress application (Olson et al., 1964). Work done from 1957 to 1960 showed that side-dressed N applications yielded an equal amount of grain as twice the amount of N fertilizer when applied pre-plant (Olson et al., 1964).

Blackmer et al. (2000) conducted intensive sampling within and between bands left by anhydrous applicators and found a relationship between percent recovery of N as exchangeable NH_4^+ and NO_3^- and soil pH. The study suggests that areas of N deficiencies corresponded to areas of high soil pH.

Slow Release Nitrogen

As long as crops have been produced, people have been searching for ways to increase yields. These attempts have come in many ways such as improving genetics, pesticide use, a variety of tillage practices, and application of fertilizers, etc. Countless studies have shown that N fertilization is positively correlated to grain yields. Furthermore, studies have shown that availability of N during certain stages in plant growth can lead to increased yields. Several different strategies have been employed in efforts to achieve this result. The idea of a fertilizer that could be applied before planting and yet provide nutrition to the plants for the entire growth season is not a new one. As early as 1907, a United States patent was granted on an impregnating and coating process to be used in the production of a slow-release fertilizer (Powell, 1968).

Some of the benefits of a slow or controlled-release fertilizer include: fewer passes with machinery (which can reduce soil compaction), less N fertilizer contamination of streams and ground water due to more efficient use, and greater availability of fertilizers at critical points in the plant's lifecycle.

There are several methods by which slow-release properties have been conferred to crop fertilizers. One approach has been to alter the chemical or physical characteristics of the fertilizer material, for instance by bringing about a reduction in the product solubility. Another is to supply a covering to the fertilizer granules that is water-resistant or impermeable. The desired effect of these mechanisms is to reduce the rate of nutrient release from the fertilizer material causing it to become gradually available.

Two terms are commonly used to describe delayed release fertilizers: controlled release and slow release. Although there are no official definitions of these terms, Trenkel (1997) suggests that controlled release refers to fertilizers in which a soluble fertilizer material is coated or encapsulated by an insoluble material which allows a slower release of the fertilizer, and slow release refers to fertilizers which are themselves insoluble and must be microbially decomposed to release their fertilizer material.

Urea-Formaldehyde Nitrogen Fertilizer

One type of slow release fertilizer is urea-formaldehyde (U-F). Yee and Love (1946) demonstrated, in the laboratory, that urea and formaldehyde could be combined in a condensation reaction to produce polymers of varying length with various degrees of solubility in hot or cold water. The chemistry for U-F as a fertilizer was patented in Germany by BASF in 1924, 1947 in the United States (Trenkel, 1997), and was first marketed in 1955 (Powell, 1968).

Many variables in the process of creating U-F fertilizers such as pH, temperature, reaction time, urea-formaldehyde ratio (Banerjee and Srivastava, 1979), degree of dilution and catalyst addition can impact the solubility of the fertilizer and therefore should be closely controlled to assure the product has agronomic value (Powell, 1968). The main issue is how to obtain the correct balance between the various condensation products. If mild conditions are used, too much of the nitrogen will be in a soluble form; under more rigorous conditions, however, compounds may be formed that are too slow in release. The length of the polymer chains and their solubility affect the rate of available nitrogen released (Hayes et al., 1965; Kaempffe and Lunt, 1967). Three different fractions, of several lengths, of polymers are typically present in the urea-formaldehyde resins: (i) cold water soluble (CWS), (ii) cold water insoluble but hot water soluble (HWS), and (iii) hot water insoluble (HWI) fractions (Sasson, 1979). The CWS fraction (25 °C) contains residual urea and the shortest length polymers; the nitrification rates of this fraction are comparable to urea (Hays et al., 1965, Hays and Haden, 1966). The HWS fraction (100 °C) includes polymers of intermediate chain length which are nitrified slowly (Kravolec and Morgan, 1954; Trenkel, 1997). The HWI fraction has a low mineralization rate due to the presence of the longest polymer chains whose N is unavailable or extremely slow release (Sasson, 1979; Tlustos and Blackmer, 1992). Tlustos and Blackmer (1992) found that the release of N from the hot water soluble fraction (HWS) in an U-F fertilizer is insignificant in neutral and alkaline soils, and that the cold water soluble fraction (CWS) behaves like a mixture of urea and inert materials in alkaline soils. Armiger et al. (1948) found that when compared to soluble inorganic and natural organic N sources, urea formaldehyde had a lower initial response but a relatively greater response in the later stages of growth as evidenced by dry weight of clippings of perennial ryegrass and Bermudagrass.

Armiger et al., (1951) concluded that; (1) – the overall efficiency of properly formulated urea formaldehyde material equals or exceeds that of conventional nitrogen fertilizers in respect to long season crops, and (2) – single applications of urea formaldehyde may be made at higher nitrogen rates than would be feasible with more soluble nitrogen sources. These findings did not agree with those of Gonzalez (2005) who found that most of the N applied in a urea treatment can be recovered within 7 to 15 days after application. U-F fertilizers in the study had lower percentage recoveries, with only 60 to 80% N recovered from these products in all the soils examined. Kralovec and Morgan (1954) estimated that 55 to 60 percent of the water-insoluble nitrogen in urea-formaldehyde is nitrified in about six months in an average soil. The water soluble portion nitrifies quite rapidly and nitrification reaches completion in about a month.

The decomposition of urea-formaldehyde fertilizers, and therefore the N release, is a multi-step process that varies depending on the product. Since the U-F mineralization is similar to urea nitrification, the release is affected by temperature, moisture, pH, microbial activity, etc. (Hadas and Kafkafi, 1974; Sasson, 1979; Trenkel, 1997). Fuller and Clark (1947) also concluded that microbiological activity is necessary for the conversion of urea formaldehyde to nitrate, and that the carbon in urea formaldehyde appears to promote microbiological activity.

Windsor and Long (1956) investigated the effect of soil pH on urea-formaldehyde mineralization. They found nitrification greatest in soils having initial pH values in the approximate range 5.5 to 6.0, which agrees with Basabara (1964) who reported 2 to 5% higher nitrate production from U-F compounds in soils with an initial pH 5.7 than in soils having an initial pH 7.0. Growth and metabolism of nitrifying bacteria is optimal in the neutral to slightly alkaline range (pH 7-8). Complete nitrification is also a pH dependant process.

In addition to use of polymers containing fertilizers in their chemical composition some slow release fertilizers make use of polymers (non-nutrient containing) or other compounds as coatings for soluble fertilizer materials. One material used to achieve this end has been wax. From findings of this literature review there have been at least two methods in which wax has been utilized. One is by dispersing fertilizers in molten wax creating a fertilizer suspension, then cooling the wax and forming it into a granular fertilizer. Another is to provide a wax coating to the fertilizer material. Wax is a water resistant material, therefore the release rates of wax coated fertilizers are controlled by chemical and/or mechanical breakdown the wax, and the wax to fertilizer ratio (either the thickness of the coating or the amount of fertilizer in the wax suspension). Another type of fertilizer coating uses polymers to delay the release of soluble fertilizer materials. This method relies on soil chemical or microbiological conditions to break down all or part of the coating. Once the coating has been breached, soil water can enter and dissolve the fertilizer material then leaking out of the capsule. Work has been done on recent polymer coatings to assure there is no persistence in the soil which could cause environmental impacts.

The previously mentioned fertilizer coatings are composed of inert materials, which reduce the amount of available nutrients in the fertilizer because there is a smaller percentage of nutrient per unit mass of fertilizer. One fertilizer option that overcomes this issue is the use of elemental sulfur as a fertilizer coating, as some soils exhibit a benefit in fertility with the addition of sulfur. It has been found, though, that the sulfur coating is too porous, due to its fragility in normal fertilizer handling and application, to serve as an effective coating material. In light of these findings petroleum based products have been added to the exterior of sulfur coated fertilizer granules to act as a sealant and delay release of fertilizer materials (Powell, 1968).

Potential drawbacks of slow-release fertilizers are: greater cost, unintended nutrient release rate due to unfavorable climatic conditions, and mechanical damage to coatings.

CHAPTER 2.

EFFECT OF U-F ON PRODUCTION OF CORN

Materials and Methods

Description

The study was conducted over two growing seasons (2004 and 2005) at two locations in Iowa: the North Central research farm (KNW) at Kanawha (2004 and 2005), the Curtiss Farm (CSS) at Ames (2004 and 2005), and for one year on a local cooperator's field adjacent to the Southeast research farm (CFV) at Crawfordsville (2004). Cultural practices at all locations are listed in Table 2.1, including population, which was used to calculate biomass ha^{-1}. The soil type the experiments at Ames and Kanawha were conducted on Nicollet (Aquic Haplaquolls), and at Crawfordsville the soil type was Otley (Typic Argiudolls).

Table 2.1. Cultural practices for all years and locations in the study

Location / Year	Planting Date	Hybrid	Population seeds / ha	Harvest Date
2004				
Ames	April 27	DeKalb 60-17	68,419	October 14
Crawfordsville	April 14	DeKalb 63-79	74,100	October 16
Kanawha	April 28	DeKalb 53-32	79,040	October 16
2005				
Ames	May 4	DeKalb 60-15	73,853	October 8
Kanawha	April 30	DeKalb 53-32 Bt	74,100	October 15

Treatments were arranged as a factorial in a randomized complete block design with four replications. Each experimental unit measured 4.6 m by 12.2 m, and contained six rows of corn spaced 76 cm apart. The Nitamin (34% N) and UAN (32% N and 28% N in 2005 and 2004, respectively) liquid fertilizers were applied in the spring before the corn was planted, and incorporated within twenty-four hours of application to reduce loss due to volatilization. The fertilizer application was done with a single plot spray applicator. Nitrogen rates for all combinations of sites and years were: 0, 56, 112, 168, and 224 kg N ha^{-1}. The Nitamin fertilizer was diluted with water (1:1) to reduce the viscosity, increasing the accuracy of application. The corn crops followed soybeans in both years at the North Central Research Farm and at the cooperator's farm in Southeast Iowa in 2004. The experiment was placed on continuous corn at the Curtiss Farm location.

The crops were evaluated several times throughout each growing season to check general plant health and variable damage due to: insect feeding, disease, and weather events.

Grain Yield and Analysis

The center rows of each plot were harvested (three rows at Kanawha and Crawfordsville and two rows at Ames) with a combine (hand harvested at Ames in 2005). The protocol for hand harvesting was to collect all ears from center two rows of each plot (excluding the first and last 3.4 m). Grain weights and moisture content were recorded from instruments in the combine (for Ames 2005 corn was shelled by both manual and mechanical methods, weighed by combine and free standing instruments, and moisture was determined with a Dickey-John moisture tester). Yield was calculated and adjusted to reflect yield at 0% grain moisture. Chemical analysis was conducted as follows: A 0.25g sub-sample was digested using Hach Digesdahl Digestion Apparatus, using the Hach Plant Tissue and Tissue Analysis System (Hach Company, 1988), with concentrated sulfuric acid (36 *N* H_2SO_4) and hydrogen peroxide (50% H_2O_2). The digest was analyzed to determine percent N by using a modified Nessler Method test and a Hach DR/3000 Spectrophotometer (DR/3000 Procedure Code N.10), as described in the method for Nitrogen Analysis in Total Plant Tissue (Hach Company, 1988). Nitrogen uptake was calculated as an increase over the N in the control.

Plant Vegetative Tissue Production and Analysis

Whole plant samples were collected after the plants reached physiological maturity. A sample consisted of the entire above ground, vegetative tissue of six plants. Those selected were the first three plants of each of the center two rows in each plot. The plant samples were chopped and weighed. A sub-sample was taken weighed, dried at 60°C for a minimum of twenty-four hours, weighed, and ground. The dry weight of the sub-sample was used to calculate biomass produced per hectare. Total nitrogen content and uptake of the vegetative biomass was determined by the same procedure as was used to determine total nitrogen content of grain.

Soil Sampling and Analysis

Soil samples were collected four times for each combination of site and year. The timing of the samples was: post-emergence (mid May), mid-season (mid July), physiological maturity (early to mid September), and post-harvest (late October). Three cores were randomly taken to a depth of 30 cm from the area between the center two rows of each experimental unit (18.6 m^2) to compose a sample. Additionally, the post-harvest sample set also contained samples collected from a depth of 30 – 61 cm.

The soil samples were dried at 60°C for a minimum of twenty-four hours, and ground to pass through a 2 mm sieve. A 10 g sub-sample was weighed and extracted with 50 ml 2 *M* KCl solution. The extract was filtered and analyzed for NO_3-N and NH_4-N using a QuickChem AE Automated Ion Analyzer, by the QuickChem Method 12-107-04-1-B (Lachat Instruments, 1992) for NO_3-N and QuickChem Method 12-107-06-2-A (Lachat Instruments, 1993) for NH_4-N.

Data Analysis

Statistix 8 (Analytical Software, 2003) was used to analyze the data. Analysis for each combination of site and year, and material was done separately. The factors analyzed were replication, N material, N rate, and N material * N rate. Nitrate-N and NH_4-N content of the soils were also analyzed separately for each combination of site and year. The factors analyzed were replication, N material, N rate, time, N material * N rate, N material * time, N rate * time, N material * N rate * time. Differences were considered to be significant at the $p>F = 0.05$ level.

In the event that outlying data were present SAS 9.1 was used for analysis, for all data, data by year and fertilizer material, as well as each combination of site and year, and the same set of factors were analyzed. Outliers were identified and analyzed using residual graphs, and were determined to be non-representative data if they were greater than three standard deviations from the experiment mean, when analyzed by single site and year combinations, and four standard deviations when more than one site or year is included in the data set. A log transformation was employed if necessary to maintain the validity of the equal variance requirement for analysis.

2004 Results

Curtiss Farm Location

Grain Production

Only N rate significantly affected grain yield ($p>F = <.0001$) (Table 2.2). Plots treated with UAN had a higher grain yield, 270 kg ha^{-1}, which represents a 5.9% advantage. Available soil N, as measured by yields in the control plots, was quite similar as yield averaged over all treatments, a 4.7% difference (Table 2.4). Although the control plot yields were similar, an advantage was observed at three of the four treatment levels in plots treated with UAN, due to the variability of the yields among the UAN treatments. Nitamin had a higher yield at the 112 kg N ha^{-1} rate, with the greatest advantage in the 224 kg N ha^{-1} treatment, 1,375 kg ha^{-1} more in the UAN treatment (9.5% increase over the same treatment rate with use of Nitamin). The average yield increase per additional 56 kg ha^{-1} was also greater in the UAN treatments than Nitamin, 1,033 kg ha^{-1} to 773 kg ha^{-1}.

Grain N uptake was not affected by treatments (Table 2.2). Plots treated with UAN had higher N uptake than those receiving Nitamin treatments in all but one N rate, 112 kg N ha^{-1}, for grain N uptake (Figure 2.1). In both fertilizer materials the increase from the 168 to the 224 kg N ha^{-1} treatment resulted in an increase of N uptake, 10 – 20 kg N ha^{-1} (Figure 2.1). This created an irregularity in the percent uptake results causing the generally decreasing percentages to increase at the highest treatment rate.

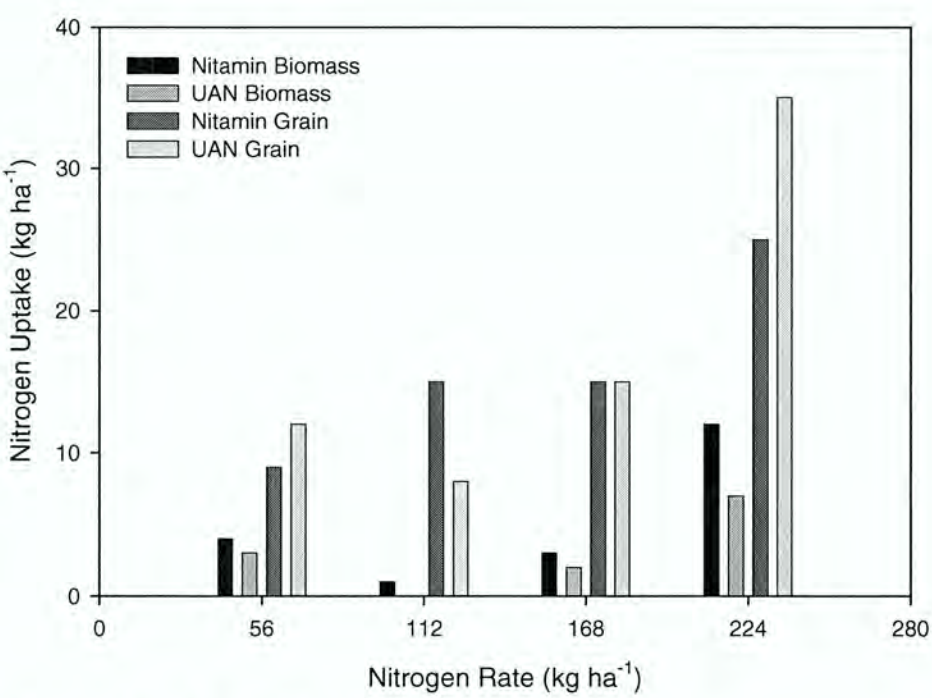

Figure 2.1. Curtiss Farm N uptake in grain and biomass, 2004

Table 2.2. Curtiss Farm yield results and N uptake, 2004

		Biomass			Grain		
N Material	**N Rate**	**Yield**	**N uptake**		**Yield**	**N uptake**	
		kg ha^{-1}		%	kg ha^{-1}		%
Nitamin	0	2265			2575		
	56	3483	4	7	3888	9	17
	112	3074	1	1	4656	15	13
	168	3076	3	2	4691	15	9
	224	4461	12	6	5669	25	11
Average		**3272**	**5**	**4**	**4296**	**16**	**13**
UAN	0	2773			2702		
	56	3657	3	6	4530	12	21
	112	3217	0	0	3825	8	7
	168	3252	2	1	4941	15	9
	224	4407	7	3	6833	35	16
Average		**3461**	**3**	**3**	**4566**	**18**	**13**
Statistics				p>F			
N Rate		*0.0103*	*0.2788*		*<.0001*	*0.5781*	
N Material		*0.9672*	*0.1751*		*0.1710*	*0.9170*	
*N Rate * N Material*		*0.7303*	*0.6638*		*0.1345*	*0.9849*	

Vegetative Biomass Production

Yield of vegetative biomass was affected only by N rate (p>F = 0.0103) (Table 2.2). As in grain yield, the production of biomass was greater in plots treated with UAN, an average advantage of 189 kg ha^{-1} representing a 5.1% increase. The increase in yield of biomass per additional 56 kg ha^{-1} was greater in plots treated with Nitamin, 140 kg ha^{-1} more produced in Nitamin plots. This is partially due to a large difference in the yields of the control plots, a difference of 508 kg ha^{-1} (18.3%). There was a considerably lower yield for the Nitamin treated control plots, the

Nitamin treatments had a slightly greater yield of biomass at the maximum N application rate, 54 kg ha^{-1} more biomass.

There are no discernable trends in biomass N uptake, and no statistically significant treatments (Table 2.2). The 112 kg N ha^{-1} UAN treatment rate had no N uptake over the amount taken up by the control plot (Figure 2.1), even though this treatment yielded over 950 kg ha^{-1} more biomass than the control. There was a minimal increase in uptake and percentage uptake of N in biomass by plots treated with Nitamin as a fertilizer source, 2 kg ha^{-1} and 1% advantage, respectively.

The total N uptake by grain and biomass, as a percent of the N rate applied, was relatively low, an average of 21 kg N ha^{-1} (15%) for plots treated with either fertilizer material (Table 2.2). The range of uptake among N rates in each material was not substantial, with a maximum difference 27 kg ha^{-1}, between 112 and 224 kg N ha^{-1} UAN treatments, and did not follow generally increasing patterns regarding trends between increasing application rates.

Soil Analysis

Soil NH_4-N was not affected by treatments. None of the Nitamin fertilizer treatment rates yielded a larger amount of soil NH_4-N than was present in the control. For plots treated with UAN as a fertilizer source there was no greater than 4% of the amount applied that was present as NH_4-N in any treatment rate. The average amount of N present as NH_4 was 2 kg ha^{-1} which represents 1% of the applied fertilizer (Table 2.4).

Soil NO_3-N was significantly affected by both fertilizer material and N rate (p>F = <.0001 and 0.0121, respectively). Both fertilizer treatments demonstrated the expected increase of No_3-N present with increasing N application rate. Plots treated with UAN had larger average amounts, including a larger range of response, and percentages of NO_3-N present in the soil at the times of sampling, an average advantage of 3 kg ha^{-1} or 2% (Table 2.4).

Kanawha Location

Grain Production

Grain yield was significantly affected only by N rate (p>F = <.0001) (Table 2.3). Plots treated with UAN yielded 167 kg ha^{-1} more grain, and had a greater increase for each additional 56 kg ha^{-1} of N applied, 275 kg ha^{-1}. Grain yields in the control plots were similar, only a 6.1% difference, thus the increases in yields are representative of the effects of the fertilizer treatments applied. The maximum yield of the UAN treatments was obtained in the 224 kg N ha^{-1} rate, 7,812 kg ha^{-1}, which was slightly more than the maximum yield from the Nitamin treated plots, 7,117 kg ha^{-1}, achieved in the 168 kg N ha^{-1} application rate (Table 2.3). This is a difference of 695 kg ha^{-1}, which is an 8.9% increase in maximum yield.

The fertilizer material used had a significant effect on the N uptake of grain (p>F = 0.0002), but no other factor was significant. There was an increase of N uptake with each increasing application rate observed in both fertilizer types. Plots treated with UAN had greater uptake of N averaging a 43% increase over those treated with Nitamin. The maximum grain uptake amounts were observed at the 224 kg N ha^{-1} treatment rate, 39 kg ha^{-1} for UAN and 21 kg ha^{-1} for Nitamin (Figure 2.2). The maximum uptake for the Nitamin treated plots was only 1 kg ha^{-1} higher than the 168 kg N ha^{-1} application rate for the UAN treatment (Table 2.3). A similar trend was observed in the percentage uptake of N by both fertilizer materials, UAN treatments averaged 4% greater uptake than Nitamin treated plots.

Vegetative Biomass Production

Vegetative biomass production was not affected by treatments (Table 2.3), but there were trends present in the data. UAN treated plots yielded more biomass than plots treated with Nitamin, 489 kg ha^{-1} (11.8% increase). Nitamin treated plots demonstrated a greater benefit to additional fertilizer, an average of

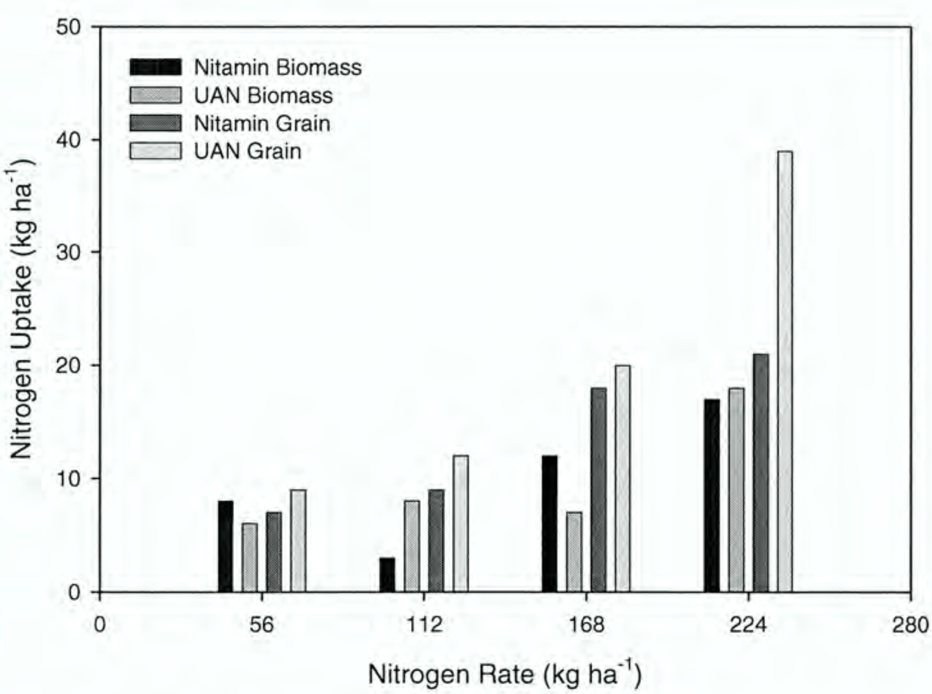

Figure 2.2. Kanawha N uptake in grain and biomass, 2004

Table 2.3. Kanawha yield results and N uptake in, 2004

		Biomass			Grain		
N Material	N Rate	Yield	N uptake		Yield	N uptake	
		kg ha^{-1}		%	kg ha^{-1}		%
Nitamin	0	2417			5640		
	56	3845	8	14	6173	7	12
	112	2928	3	3	6282	9	8
	168	3806	12	7	7117	18	11
	224	5262	17	8	7056	21	9
Average		**3652**	**10**	**8**	**6454**	**14**	**10**
UAN	0	3068			5297		
	56	3832	6	10	6245	9	15
	112	4569	8	7	6486	12	10
	168	3890	7	4	7267	20	12
	224	5346	18	8	7812	39	17
Average		**4141**	**10**	**7**	**6621**	**20**	**14**
Statistics				p>F			
N Rate		*0.0552*	*0.2175*		*<.0001*	*0.1907*	
N Material		*0.3412*	*0.1940*		*0.4363*	*0.0002*	
*N Rate * N Material*		*0.8229*	*0.9345*		*0.6089*	*0.2414*	

141 kg ha^{-1} increase for each successive treatment rate. This difference is a result of differences in the biomass yields of the control plots for the two fertilizer materials, UAN yielded 651 kg ha^{-1} more in the control, which is an 21.2% increase, although this value is not indicative of the biomass yield response to additional fertilizer. There is not a consistent pattern of increase in yield due to increasing N application rates. The maximum yields for the fertilizer materials are quite similar, 5,346 kg ha^{-1} for UAN and 5,262 kg ha^{-1} for Nitamin treated plots (a 1.6% difference in maximum yields) (Table 2.3).

Nitrogen uptake by vegetative biomass was not affected by treatments (Table 2.3). As with the yield of biomass there was a general trend of an increase in response with each increase in N rate, although not all data fit this trend. The fertilizer treatments had the same average uptake, Nitamin treatments had an advantage of 1% in percentage uptake. Plots treated with UAN had a larger range in N uptake per increase in fertilization rate, although this was minimal.

The total N uptake by grain and biomass, as a percent of the N rate applied was moderately low, only 24% for plots treated with Nitamin and 30% for plots receiving UAN (Table 2.3). The range of uptake between N rates in each material was quite large, 217% increase in Nitamin and 280% increase in UAN treatments, and followed a generally increasing trend between successive application rates.

Soil Analysis

Soil NH_4-N was not affected by treatments (Table 2.4). No plot treated with UAN had larger amounts of soil ammonium-N than the control plot. There were two treatment rates that had NH_4-N levels higher than the control, these increases averaged only a 2 kg ha^{-1} or 1% advantage.

Soil No_3-N was significantly affected by both N rate and fertilizer material ($p>F = <.0001$ and 0.0017, respectively) (Table 2.4), but not the interaction of those factors. Nitrate-N levels increased with increases in fertilizer rate. UAN had 50% higher soil NO_3-N levels than Nitamin treated plots. The percent of NO_3-N in the soil compared to the N rate applied was also higher in UAN treated plots, average of 4% greater nitrate-N present.

Table 2.4. Average soil NH_4^+ and NO_3^- results from all years and locations **(contin. on pg. 38)**

NH_4^+

N Material	**N Rate**	**2004** CSS		KNW	
		kg ha⁻	%	kg ha⁻	%
Nitamin	56	(-6)	0	0	0
	112	(-5)	0	1	1
	168	(-4)	0	5	3
	224	(-8)	0	0	0
Average		**(-6)**	**0**	**2**	**1**
UAN	56	(-2)	0	(-3)	0
	112	4	4	0	0
	168	2	1	(-2)	0
	224	5	2	(-1)	0
Average		**2**	**1**	**(-2)**	**0**
Statistics			p>F		
N Rate		0.1412		0.7109	
N Material		0.3515		0.8362	
*N Rate * N Material*		0.0999		0.6559	

N Material	**N Rate**	**2005** CSS		KNW	
		kg ha⁻	%	kg ha⁻	%
Nitamin	56	(-1)	0	(-1)	0
	112	2	2	(-2)	0
	168	(-4)	0	3	2
	224	1	0	0	0
Average		**(-1)**	**0**	**0**	**6**
UAN	56	1	2	(-1)	0
	112	2	1	0	0
	168	(-1)	0	0	0
	224	2	1	(-1)	0
Average		**1**	**1**	**(-1)**	**0**
Statistics			p>F		
N Rate		0.0133		0.6285	
N Material		0.9510		0.0504	
*N Rate * N Material*		0.0141		0.8789	

NO_3^-

N Material	N Rate	2004 CSS		KNW	
		kg ha-	%	kg ha-	%
Nitamin	56	4	7	5	9
	112	7	6	7	6
	168	12	7	12	7
	224	20	9	16	7
Average		**11**	**7**	**10**	**7**
UAN	56	3	5	6	11
	112	10	9	14	13
	168	15	9	14	8
	224	28	13	25	11
Average		**14**	**9**	**15**	**11**

Statistics	p>F	
N Rate	<.0001	<.0001
N Material	0.0121	0.0017
*N Rate * N Material*	0.6752	0.2342

N Material	N Rate	2005 CSS		KNW	
		kg ha-	%	kg ha-	%
Nitamin	56	1	2	2	4
	112	5	4	7	6
	168	5	3	10	6
	224	9	4	15	7
Average		**5**	**3**	**9**	**6**
UAN	56	2	4	2	4
	112	2	2	2	2
	168	4	2	6	4
	224	5	2	2	1
Average		**3**	**2**	**3**	**2**

Statistics	p>F	
N Rate	<.0001	<.0001
N Material	0.0017	<.0001
*N Rate * N Material*	0.0234	<.0001

2005 Results

Curtiss Farm Location

Grain Production

Grain yield was significantly affected by both application rate and fertilizer material ($p>F$ = <.0001). The interaction of these terms was also significant ($p>F$ = 0.0048) (Table 2.5). The actual advantage for the Nitamin material over UAN, averaged over all treatment rates, was 1,464 kg ha^{-1} at 0% moisture (6,085 kg ha^{-1} for plots treated with Nitamin and 4,621 kg ha^{-1} for those treated with UAN), a 24.1% increase in average yields. The average increase in grain yield per additional 56 kg ha^{-1} N was more than three times greater for plots treated with Nitamin opposed to those treated with UAN, 1,060 kg ha^{-1} to 280 kg ha^{-1}, as there was variability this does not imply that each increase of 56 kg ha^{-1} resulted in this reported increase. The control plots were similar with only a 5.1% difference (203 kg ha^{-1}). The difference in the range of yields produced was also quite large. Plots treated with Nitamin achieved a maximum yield of 8,042 kg ha^{-1}, an increase of 4,238 kg ha^{-1} with fertilizer application (at 224 kg ha^{-1}). Plots receiving UAN fertilization demonstrated a maximum yield of 5,125 kg ha^{-1}, an increase of 1,118 kg ha^{-1} over the control (Table 2.5).

There was not a significant effect on the uptake of N by the grain based on the type of fertilizer material used, although N rate was very nearly a significant factor at the α=0.05 level ($p>F$ = 0.0561), and the interaction was

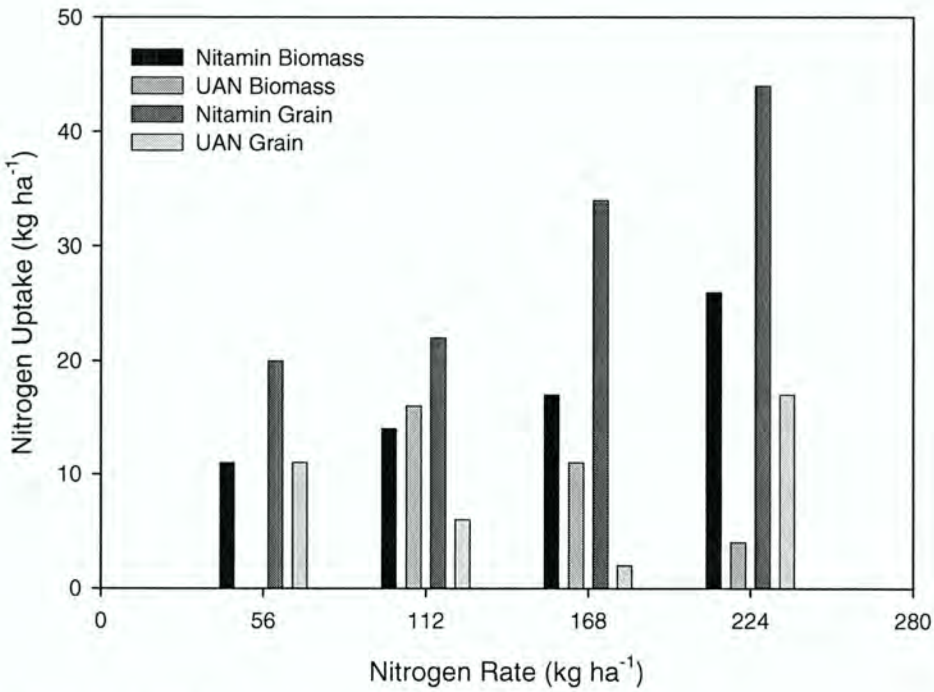

Figure 2.3. Curtiss Farm N uptake in grain and biomass, 2005

significant (p>F = 0.0294) (Table 2.5). The quantity of N taken up by the grain by plots treated with Nitamin was nearly three times the amount taken up by plots treated with UAN (30 kg ha^{-1} to 9 kg ha^{-1}) (Figure 2.3). When averaged across N rate there is still an advantage in plots treated with Nitamin over those treated with UAN (24% to 9%).

Vegetative Biomass Production

Yield of vegetative biomass was not significantly affected by any of the factors reported. There was a slightly higher average biomass production measured in plots treated with Nitamin, but this difference was only 5.5% (489 kg ha^{-1}). The control treatments were once again similar with slightly increased yields in UAN treated plots, (6.1%, 489 kg ha^{-1}). The combination of higher average yield and higher increase of yield per N rate in plots treated with Nitamin indicate their was a great range in the yield of biomass between the plots when treated with the different fertilizer materials, similar to the trend seen in grain production (2,173 kg ha^{-1} in Nitamin plots, and 1,896 kg ha^{-1} in those treated with UAN). A difference in these figures is that Nitamin treated plots had their low and high in the 0 and 224 kg ha^{-1} treatments, respectively, and in plots receiving UAN the low and high yields were in the 56 and 112 kg ha^{-1}, respectively (Table 2.5).

Table 2.5. Curtiss Farm yield results and N uptake, 2005

		Biomass			Grain		
N Material	**N Rate**	**Yield**	**N uptake**		**Yield**	**N uptake**	
		kg ha^{-1}		%	kg ha^{-1}		%
Nitamin	0	7556			3804		
	56	8843	11	20	5685	20	35
	112	8740	14	12	5971	22	20
	168	9298	17	10	6925	34	20
	224	9729	26	11	8042	44	20
Average		**8833**	**17**	**13**	**6085**	**30**	**24**
UAN	0	8045			4007		
	56	7343	0	0	4692	11	20
	112	9239	16	15	4747	6	5
	168	8731	11	7	4536	2	1
	224	8361	4	2	5125	17	8
Average		**8344**	**8**	**6**	**4738**	**9**	**9**
Statistics				p>F			
N Rate		*0.1668*	*0.3413*		*<.0001*	*0.7809*	
N Material		*0.2344*	*0.0563*		*<.0001*	*0.0561*	
*N Rate * N Material*		*0.3536*	*0.3584*		*0.0048*	*0.0294*	

The total N uptake by all plant tissues, as a percent of the N rate applied, had a large range, both within and between fertilizer materials (Figure 2.3). Plots treated with Nitamin averaged an uptake of 37% of N applied, ranging from 30% to 55%. Those treated with UAN averaged a total uptake of 15%, ranging from 8% to 20%. The general trend was for the lower treatment rates to have a higher N uptake.

Soil Analysis

All factors reported, N rate, fertilizer material, and their interaction ($p>F$ = <.0001, 0.0017, and 0.0234 respectively) (Table 2.4), significantly affected soil NH_4-N. Although the increases in presence of NH_4-N were minimal, there was a pattern of increasing levels with increasing N rates. The same is true of the difference between fertilizer materials, means of 5 and 3 kg ha^{-1} for Nitamin and UAN respectively.

Soil NO_3-N was significantly affected by N rate ($p>F$ = <.0001) and fertilizer material ($p>F = 0.0121$) (Table 2.4) but not their interaction. These results were dissimilar from the findings of the soil NH_4-N analysis in that UAN showed greater advantage in the level of NO_3-N. Once again the difference, although significant, is not very large on a number or percentage basis. UAN had a larger range in the values of the results, 25 kg ha^{-1}, compared to that of the Nitamin treatments, 16 kg ha^{-1}.

Kanawha Location

Grain Production

Grain yield was significantly affected by the fertilizer type (p>F = 0.0020) and N rate (p>F = .0193) (Table 2.6). The interaction was not significant for these two factors. Actual increase in grain yield of those plots receiving Nitamin fertilizer treatment over those receiving UAN was 1,150 kg ha^{-1}, when averaged across N rates. Although not the magnitude of the advantage per 56 kg ha^{-1} as reported at the Curtiss Farm Location in 2005 there was an average of greater than a 300% yield increase with each additional 56 kg ha^{-1} of Nitamin over UAN. Increase in yield per increase in fertilization rate was determined by the difference in yields of the high and low N rate although they may not have been the highest or lowest yields. This is representative of a much greater range in yields observed, a range of 2,391 kg ha^{-1} compared to 951 kg ha^{-1}, for plots treated with Nitamin and UAN respectively (the greatest yield for UAN, plots was observed in the 168 kg ha^{-1} treatment and the low was achieved in the 112 kg N ha^{-1} treatment (Table 2.6). In this experiment the control plots were similar and represent a good platform from which to make comparisons, a 4.1% difference.

N uptake by the grain was significantly affected by the fertilizer material (p>F = 0.0296) (Table 2.6), but for no other factors. Similar to grain yield, uptake of N by the grain was higher for plots treated with Nitamin, an average of 20 kg ha^{-1} compared to 10 kg ha^{-1} in UAN plots (Figure 2.4). Percent N uptake for Nitamin was also twice that of UAN (16% compared to 8%).

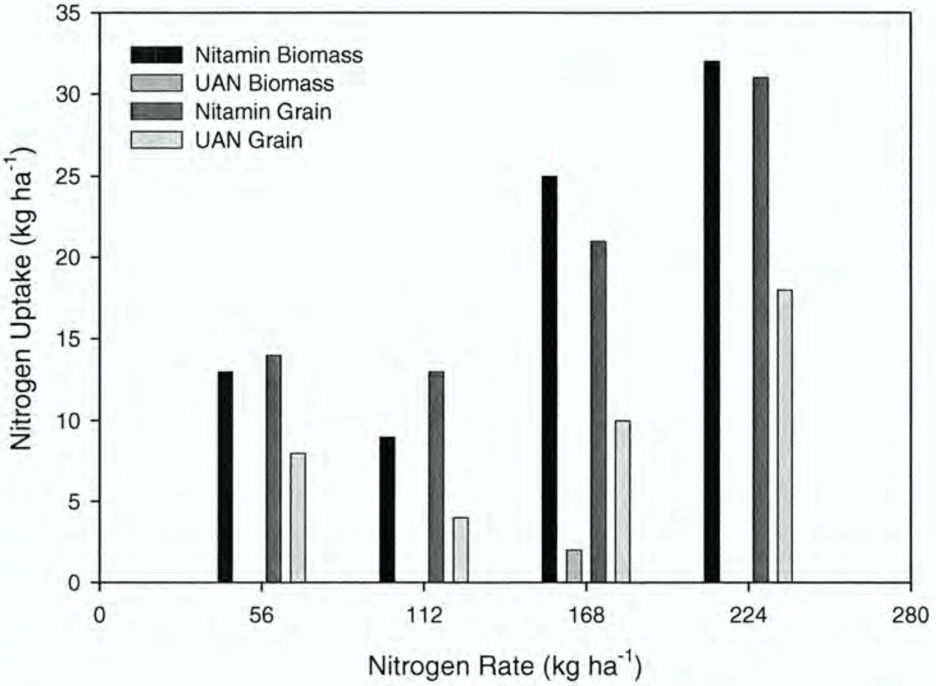

Figure 2.4. Kanawha N uptake in grain and biomass, 2005

Vegetative Biomass Production

Yield of vegetative biomass was not significantly affected by N rate, fertilizer material, or their interaction (Table 2.6). The values obtained for the UAN treatments were quite unexpected. The highest yield of biomass was in the control treatment (Table 2.6), with no discernable pattern of increase or decrease with the addition of N fertilizer. The results from plots treated with Nitamin followed a strong pattern of increasing yield with each increase in fertilization, the average increase being 490 kg ha^{-1} per additional 56 kg ha^{-1} of N. When comparing the ranges of biomass production between the two fertilizer materials it is noted that they are similar, 146 kg ha^{-1} representing a 7.5% difference, although the lowest yield for UAN was from the 112 kg ha^{-1} treatment and the high was in the control.

Table 2.6. Kanawha yield results and N uptake, 2005

		Biomass			Grain		
N Material	**N Rate**	**Yield**	**N uptake**		**Yield**	**N uptake**	
		kg ha^{-1}		%	kg ha^{-1}		%
Nitamin	0	8621			8128		
	56	9643	13	24	8778	14	24
	112	9903	9	8	9106	13	12
	168	10222	25	15	10311	21	13
	224	10579	32	14	10519	31	14
Average		**9794**	**20**	**15**	**9368**	**20**	**16**
UAN	0	10257			7795		
	56	10094	0	0	8181	8	14
	112	8445	0	0	7790	4	4
	168	10219	2	1	8741	10	6
	224	9038	0	0	8581	18	8
Average		**9611**	**1**	**0**	**8218**	**10**	**8**
Statistics				p>F			
N Rate		*0.4625*	*0.4922*		*0.0193*	*0.2113*	
N Material		*0.6307*	*0.1656*		*0.0020*	*0.0296*	
*N Rate * N Material*		*0.0601*	*0.2673*		*0.5555*	*0.6856*	

N uptake in vegetative biomass was not affected by treatments. Due to the high yield in the control treatments there was a very low amount of uptake by the plant due to the addition of fertilizer. The uptake in plots receiving Nitamin fertilization exhibited a strong pattern in N uptake (Figure 2.4). The average uptake was 20 kg ha^{-1}, 14% of applied N. This represents a range of 23 kg ha^{-1}, the lowest uptake in the 112 kg ha^{-1} treatment and the high in the 224 kg ha^{-1} treatment. There is an interesting difference in the 56 and 112 kg ha^{-1} application rates. The 56 kg ha^{-1} rate had a slightly lower yield but a greater uptake of N than did the 112 kg ha^{-1}

treatment. This suggests the 112 kg N ha^{-1} treatment had a low N concentration. Had this treatment followed the trend of the other Nitamin treatments the value it would have would be ~19.3 kg ha^{-1} as opposed to the 9 kg ha^{-1} that was obtained.

There was a large difference in total N uptake between fertilizer materials by all plant tissues (Table 2.6). There was also a large range within the N rates of the Nitamin fertilizer applications, from a low of 20 to a high of 48%. The average percentage uptake was much larger in plots treated with Nitamin than those receiving UAN fertilizer treatments, 31% uptake for Nitamin and 8% for UAN.

Soil Analysis

Soil NH_4-N was affected by both fertilizer material and N rate (p>F = <.0001) (Table 2.4). As in the other 2005 location the soil tested higher for NH_4-N when Nitamin treatments were applied, over those treated with UAN. The difference was 6 kg ha^{-1}, an averaged amount over the five sampling times, which represents a 300% increase over the UAN treatments. The percent NH_4-N in the soil compared to the rate applied followed a similar pattern. The Nitamin treated plots also had a more consistent trend in increasing NH_4-N concentration, ~4 kg ha^{-1} increase with each additional 56 kg ha^{-1} of fertilizer. All the UAN treated plots had the same values for soil NH_4-N, with the exception of the 168 kg ha^{-1} treatment.

Nitrogen rate and fertilizer material significantly affected soil NO_3-N (p>F = <.0001 and p>F = 0.0017, respectively) (Table 2.4), but their interaction was not significant. These results also mimicked those observed at the Curtiss Farm location in 2005, with UAN having higher values than Nitamin treatments, both actual amounts and percent NO_3-N in the soil compared to the rate applied increased by 50% when UAN was applied. Both fertilizer materials demonstrate a generally consistent increase in soil NO_3-N with increasing fertilization.

Data Analysis

Data from 2004 and 2005 as collected from the Curtiss Farm and North Iowa Research farm locations were analyzed using SAS 9.1 for the following factors: Year, Location, Application Rate, Treatment, Time (for soil analysis), and all interactions. Results were reported for the factors of Treatment, Application Rate, and the interaction of those terms, and were significant at the α=0.05 level. The SAS procedure used was proc glm. Residual graphs were created to analyze the data for outliers, which were determined by the following criteria: for a single combination of site and year any data greater than $\sigma = 3$ (sample standard deviation = 3), or for any analysis involving one or more sites or years $\sigma = 4$. All outliers meeting these criteria were removed from the data set for analysis. In the event that a residual graph demonstrated unequal variability a log transform was performed and the statistics reported accordingly. There were data sets in which this action did not correct the problem of unequal variability, these instances where reported when the location were discussed. All graphs were created with SigmaPlot 9.0.

Discussion

Grain yield results displayed great variability between the two years in this study, up to the highest rate of N application (Figure 2.5). Yields in 2005 were on average 1,589 kg ha^{-1} greater than in 2004. Plots treated with UAN in 2004 had slightly greater yields, a per location average increase of 219 kg ha^{-1}, but in 2005 it was the plots receiving Nitamin fertilization that had the advantage regarding grain yield, to a much greater extent in 2005, 1,307 kg ha^{-1}. The average yields, across location, for all years in the study (Figure 2.5), favored the Nitamin treatments by an average of 544 kg ha^{-1}. This change in the trends of grain yield, between the two years, suggests that some factor outside of the experimental design was beneficial for the crop production in 2005. There are several variables that may have

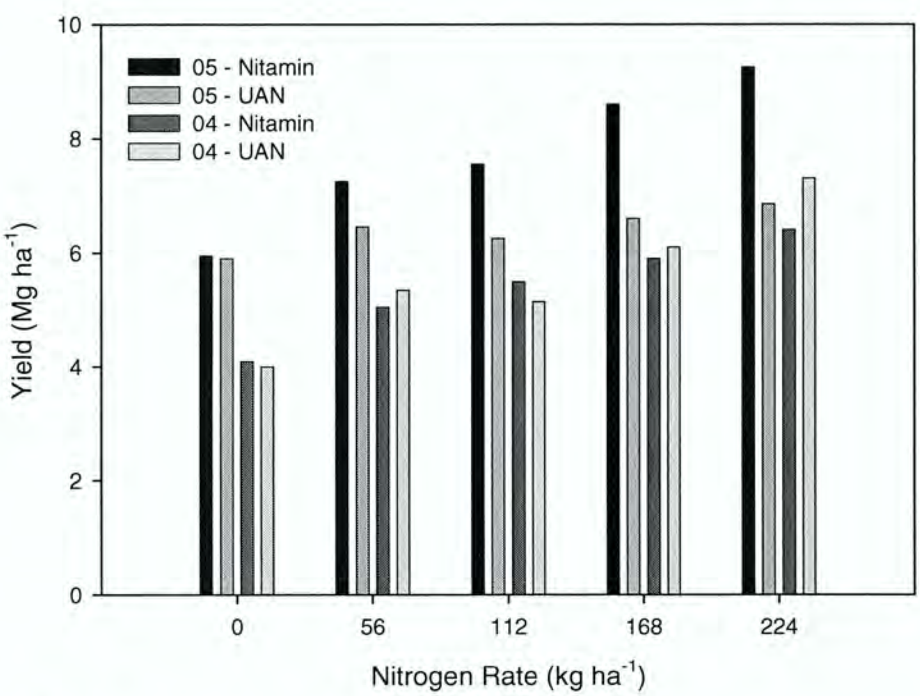

Figure 2.5. Yield comparison of all years by fertilizer type

contributed to this difference. Conditions may have been more favorable for the loss of N from UAN in 2005, through a variety of possible mechanisms, causing the lower rate of yield increase per additional unit of N. Regression slopes for yield response to UAN decreased from 1.37% in 2004 to 0.37% in 2005 (Figure 2.8). Although average yields across N rates were higher in 2005 than in 2004, the 224 kg N ha^{-1} treatment rate was the only rate at which 2004 yields were higher than those in 2005. Also, as Nitamin treatments demonstrated higher yields in 2005 (Figure 2.7), conditions may have been more favorable for the release of N from the U-F polymers, meaning that conditions may have been more favorable for increased microbial activity or for crop growth in general in 2005. This last reason may also explain part of the difference of yield between the control plots when data are separated by year, an increase of 1,880 kg ha^{-1} in 2005, as well as the increase in yield in UAN treatments in 2005 considering the low yield response to increasing N rate. Plots treated with Nitamin have greater slopes based on regression analysis than did plots treated with UAN, 1.20% in Nitamin treatments and 0.84% in UAN (Figure 2.9) which equals a 12.4 and 9.5 kg ha^{-1} increase per 1 kg ha^{-1} of N applied, respectively. With similar yields in the control treatments, an average difference of 87 kg ha^{-1}, the increase in yield per unit of additional fertilizer added from this point represents yield improvement due to fertilizer material, a difference of 734 kg ha^{-1} at the 244 kg N ha^{-1} treatment rate. The findings for yield when treated with UAN fertilizer displayed differing trends compared to those of receiving Nitamin. This may be partly due to the decreased solubility of Nitamin, which would decrease the potential for leaching, volatilization, or loss by other mechanisms. Whereas, UAN is

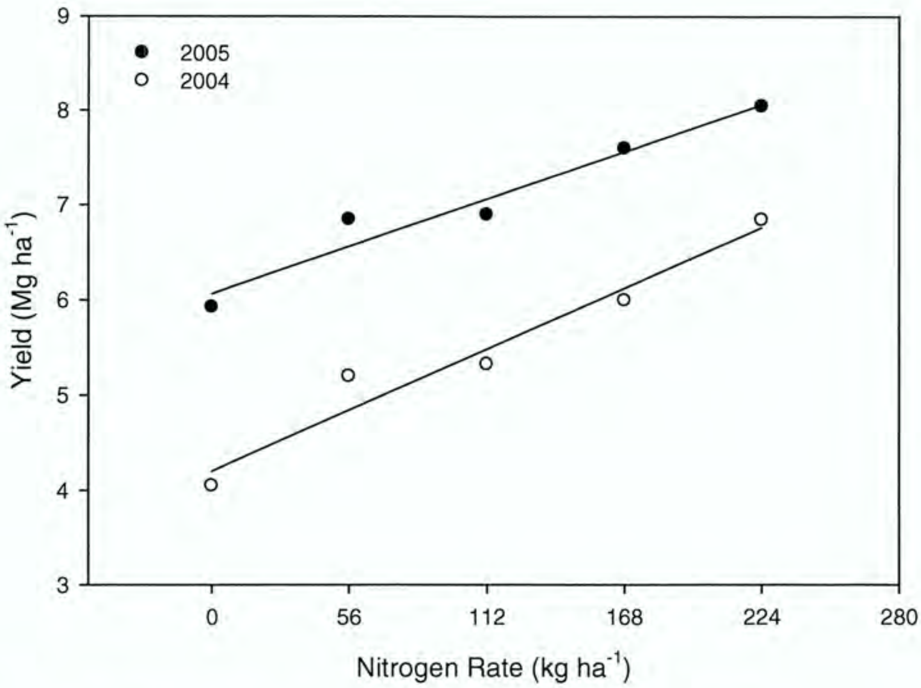

Figure 2.6. Yield comparison between 2004 and 2005 growing seasons

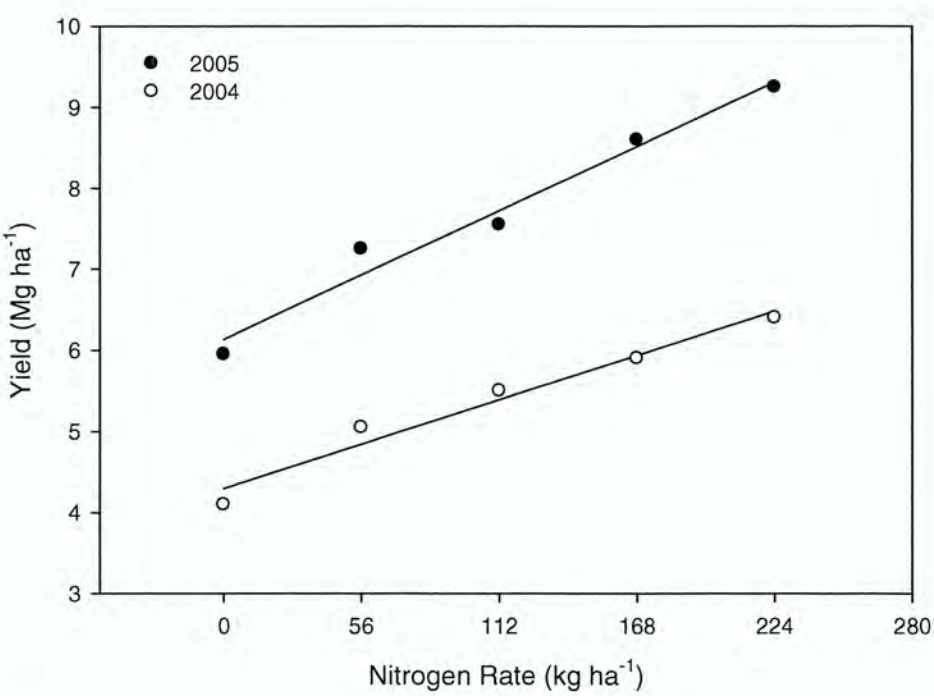

Figure 2.7. Yield comparison of plots treated with Nitamin fertilizer in 2004 & 2005

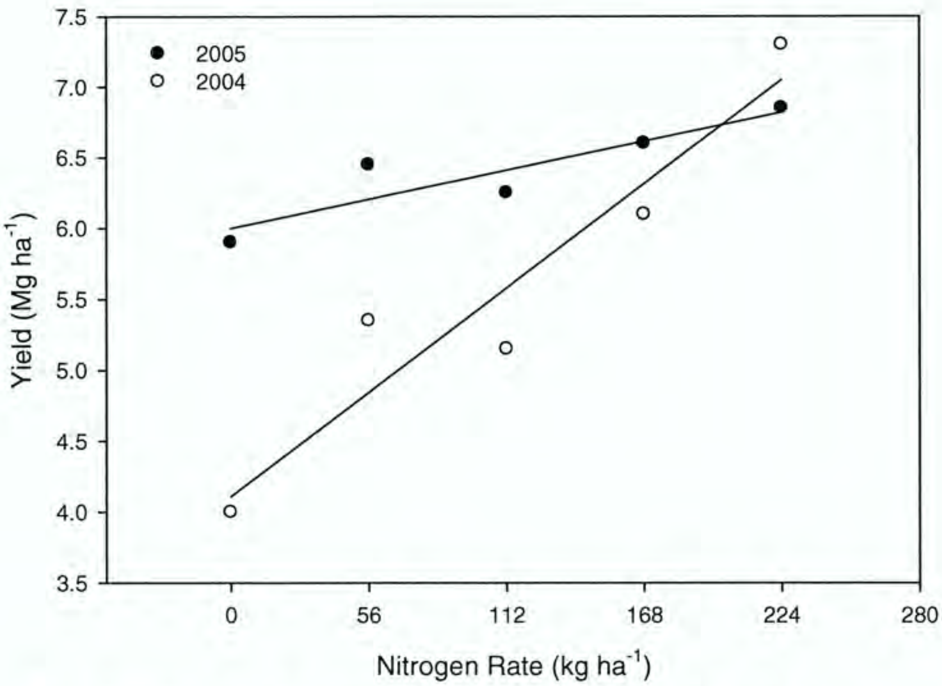

Figure 2.8. Yield comparison of plots treated with UAN fertilizer in 2004 & 2005

available within a short period of time after its application, and is determined by several factors including climate and the amount of urease present in soil. It was also seen that U-F fertilizers may have had more consistent availability of N than did UAN, on the basis of increase in yield per amount of N fertilization applied (Figure 2.9). This comparison was largely affected by the results of UAN treatments in 2005 (Figure 2.11), opposed to results in 2004 (Figure 2.10) showed little difference between fertilizer materials. There is a possibility that, as the experiment at the Curtiss Farm was conducted with the same arrangement of treatment application and at the same field location in both years, there may have been some benefit in 2005 from residual N present from the very slow releasing portions of the U-F fertilizer applied in 2004, although results from post-harvest soil sampling showed no

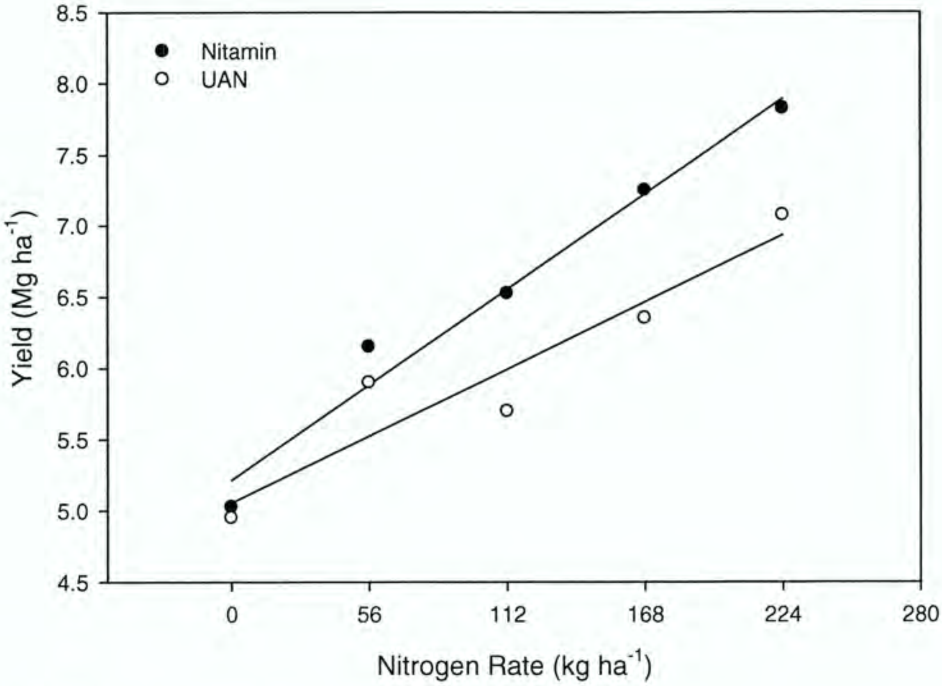

Figure 2.9. Yield comparison by fertilizer types

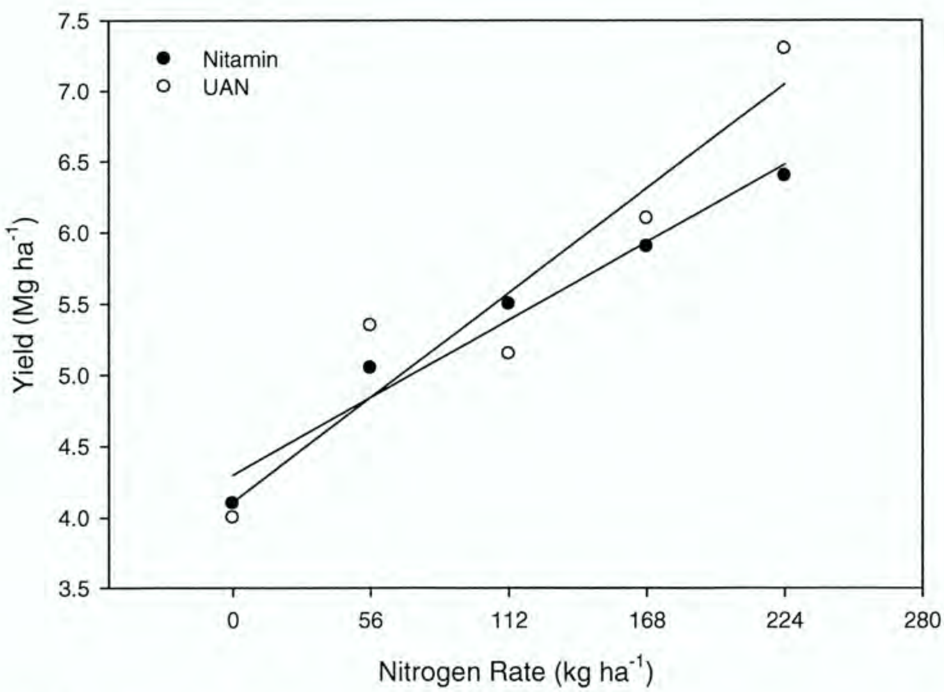

Figure 2.10. Yield comparison by fertilizer types in 2004

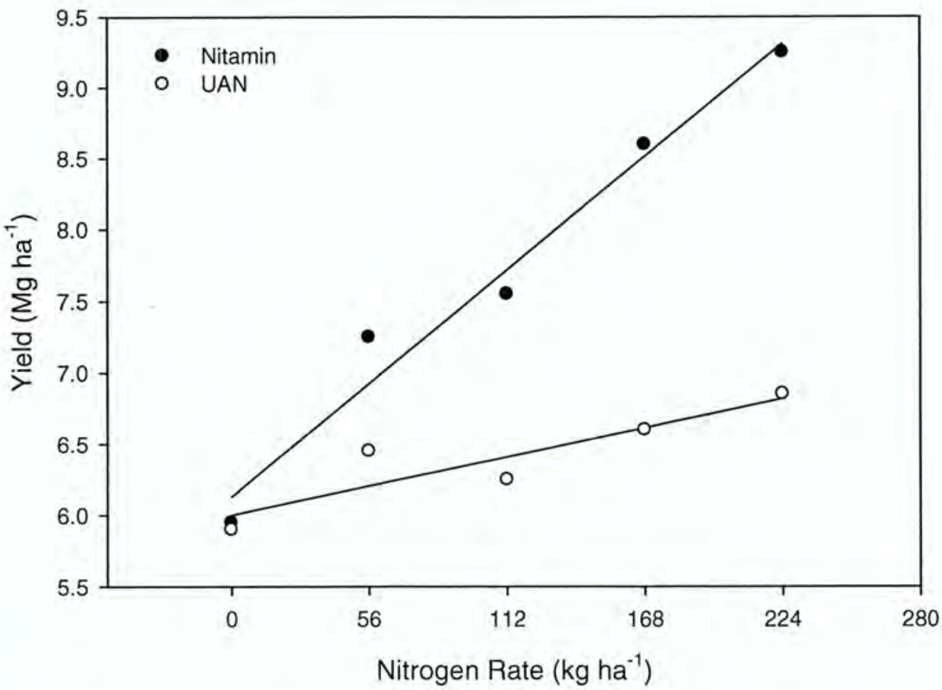

Figure 2.11. Yield comparison by fertilizer types in 2005

increase in inorganic N present over those plots treated with UAN at the Curtiss Farm location. As the N is released from U-F fertilizers by microbial action the rate it will become available for plant use or loss is determined by the activity of soil microbes. It can also be affected by microbial populations as they may immobilize soil-N for their growth and then mineralize it when they become part of the soil humic material. There were considerable differences between the two years studied, as has been discussed, both in crop performance and climatic conditions. These topics need to be addressed as they represent variables outside of the experimental model and may have caused responses, or lack there of, that were not dependant upon the fertilizer treatments. One such variable is the climatic conditions experienced during the plant's life cycle, especially during pollination. The crop begins the period of silking, exposing the receptacles for the female reproduction organs, in early to mid

July, and pollinating, shedding the male reproductive materials, shortly thereafter. The exact timing depends on several factors such as genetics, planting date, and environmental conditions experienced by the plant as they relate to early seedling vigor, but the process generally occurs in mid-July. The temperature (Figure 2.14), as reported in growing degree units (GDU) and moisture conditions (Figure 2.12) at this particular time have as great of an impact on yield potential as any other point in the plant's life cycle, with the exception of any factor resulting in the plants death. High heat and drought conditions can cause sterility of pollen, and damage to the silks produced by the ear. If the conditions were unfavorable during this time, the N levels could potentially be considered irrelevant, as yield determination would have been more greatly affected by the climate. This type of variability could explain some of the differences between the two years in the study, although timing of

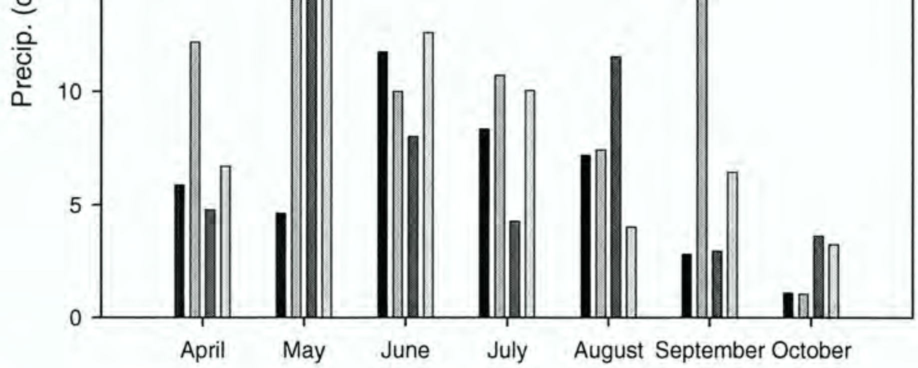

Figure 2.12. Monthly accumulation of precipitation

specific climatic conditions and how they may have affected plant growth were not part of this study, with higher yields at all nitrogen rates studied in 2005. UAN treatments had a greatly decreased response to N rate in 2005 than in 2004. One reason for this may be that the North Iowa Research farm received 80% to 150% more precipitation in April 2005 than the other combinations of sites and years (Figure 2.12). This additional moisture may have caused the nitrogen in UAN to be mobile, and leach out of the root zone. Without a significant amount of vegetative biomass present to utilize soil-N there is a greater chance for fertilizer loss by this mechanism. As plants may not emerge until mid-May this leaves approximately two weeks before the plants really start consuming nutrition from the soil, and more than a month until their N uptake rate reaches its maximum. Any precipitation received in the months of April and May has a much greater probability of causing leaching than similar amounts of rain received at other times throughout the growing season. There were also differences in rainfall during the second half of July, which is the general time period when pollination occurs, with five additional rainfall events occurring in 2005 than in 2004 during this time (Figure 2.13). This could have been detrimental to attaining maximum yield potential in 2004, the crop at the Curtiss Farm location yielded the lowest mean amounts of grain and biomass of all site year combinations.

During the months of June and July, those with the most rapid plant development, crops grown in the 2005 season received 252 additional growing degree units than during the same time in 2004 (Figure 2.14). The potential drawback to greater amounts of heat is that when corn plants enter their

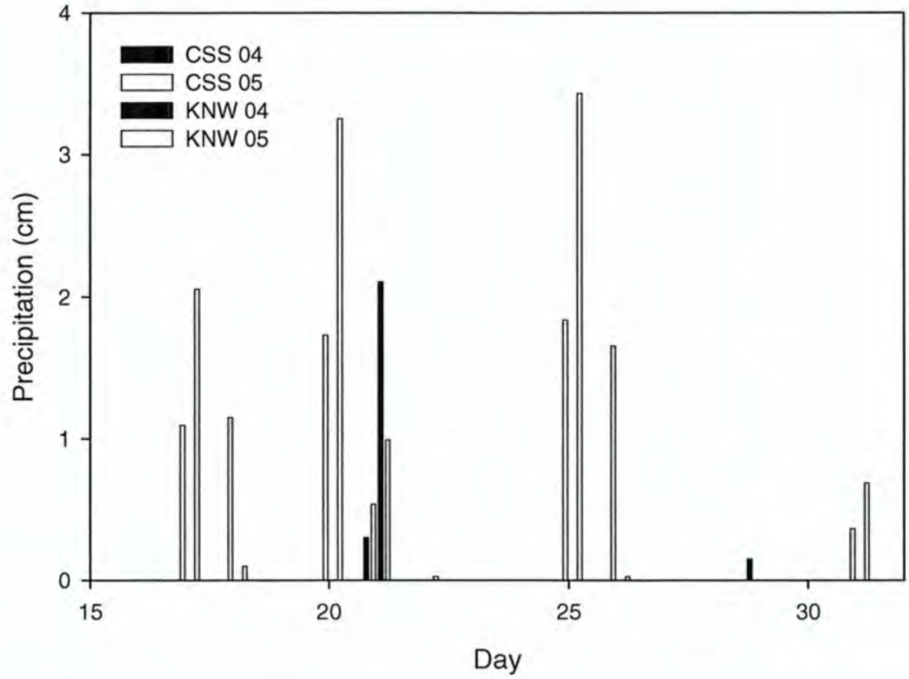

Figure 2.13. Rainfall events during pollination in 2004 and 2005.

reproductive stages high temperatures, and dry conditions, which as discussed previously, can decrease the incidence of successful pollination and can subsequently, cause a decrease potential yield.

There are several possible factors that could influence the release rate of N from the U-F fertilizer. The primary factor, though, is the level of microbial activity in the soil. Therefore, any factor, biotic or abiotic, that affects this activity will affect the fertilizer release rate. One possibility is the climate. Levels of soil moisture commonly encountered in agricultural soils are adequate to promote microbiological life, with the exception of extremes in soil moisture content. Activity is diminished with moisture contents nearing saturation due to a lack of oxygen needed for aerobic respiration, and at low moisture contents microbial activity decreases with potential

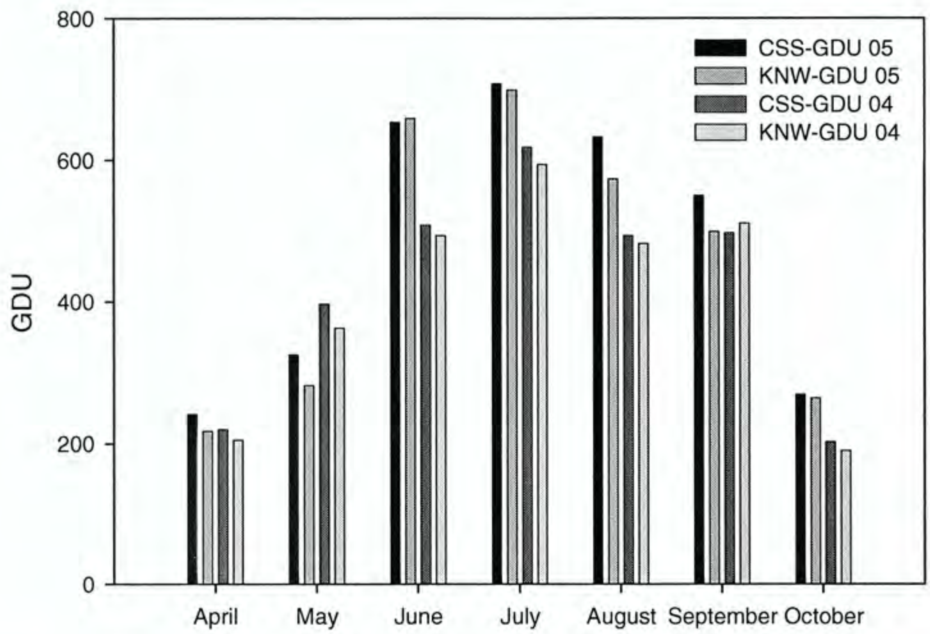

Figure 2.14. Monthly accumulation of Growing Degree Units (GDU)

desiccation of microbes and decreased mobility of substrates through water films on soil particles. This leaves temperature as the main environmental factor. According to the $Q_{10} = 2$ rule for every increase of 10°C there will be a doubling of microbial activity, this is an application of the Arrhenius relationship which describes the effect of temperature on reaction rate. Although not fully a 10 degree difference there was a difference of 3.1°C in air temperature and 2.1 °C in soil temperature, at a 10 cm depth in the months of June and July between the two years in the study. With the understanding that soil temperature varies with depth, the air and 10 cm depth soil temperatures are provided as an indication of the level of increase in soil temperature in 2005 (Figure 2.15). The months of June and July are the time in which the most rapid of growth of corn plants occur, developing from early vegetative stages to reproductive stages. The increased temperature in 2005 may

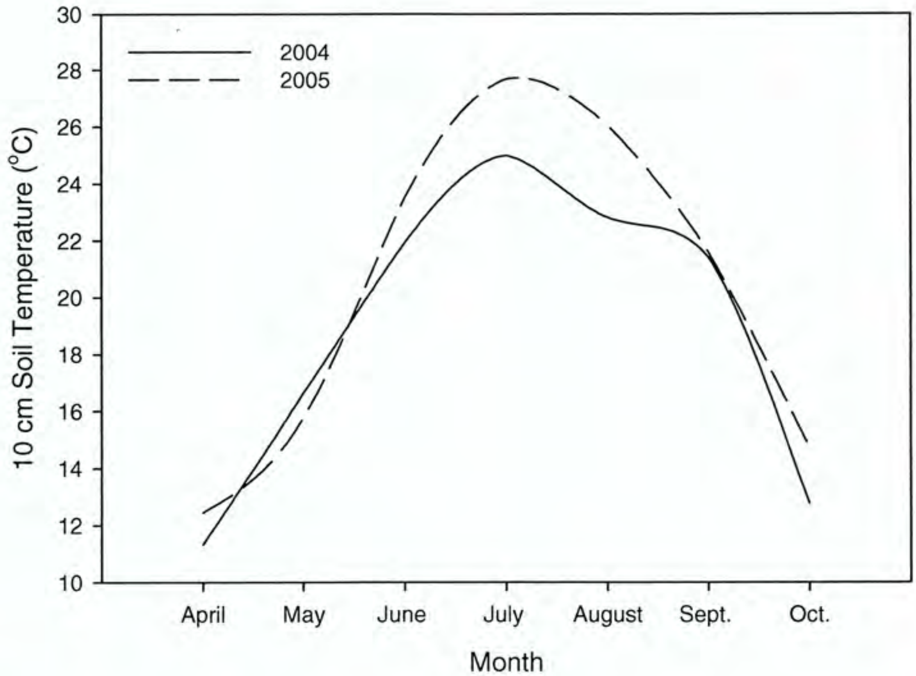

Figure 2.15. Mean monthly 10 cm soil temperature in 2004 and 2005

have increased microbial activity substantially enough to cause a greater degree or percentage release of the N from the U-F polymers, which may have contributed to the increase in yield experienced in the Nitamin treated plots in 2005 over those in 2004. When environmental factors and their effects are considered, 2005 was apparently a more favorable year for corn production, as seen in the mean grain yields of both fertilizer types in the separate years (7, 073 kg ha^{-1} in 2005 and 5,484 kg ha^{-1} in 2004) as well as the yield difference in the control plots (5,934 kg ha^{-1} in 2005 and 4,054 kg ha^{-1} in 2004. This yield difference represents a 46% increase in the grain yield of control treatments in 2005 compared to those in 2004.

CHAPTER 3.

EFFECT OF U-F ON PRODUCTION OF CORN WITH ADDITIONAL FERTILIZER APPLICATION

Materials and Methods

Description

The experiment was conducted with the same design as those located at the ISU North Central and Curtiss Farm with two exceptions. Due to spatial limitations this experiment was conducted on a grower cooperator's field immediately adjacent to the ISU Southeast Research Farm. Prior to being contacted by the research farm supervisor regarding the use of his land for this research the grower had applied a 33.6 kg ha^{-1} N, anhydrous ammonia, pre-plant starter fertilizer. Because of this the experiment was only conducted for one year, 2004, and will be discussed separately from other data. Other differences regarding this location, though not part of the experimental design, are the soil type, which was predominantly Otley, and the soil parent material. This location is located on the southern Iowa drift plain, and is a much more highly developed soil than those of the Des Moines lobe, on which the other locations are located. Cultural practices are listed in Table 2.1.

2004 Results

Crawfordsville

Grain Production

Grain yield was not significantly affected by N rate or fertilizer type (Table 3.1). The average yield for Nitamin application was 9,674 kg ha^{-1}, and that for UAN application was 9,627 kg ha^{-1}, a 0.5% difference, yield data are presented at 0% moisture. Linear regression shows a trend in yield that Nitamin plots had a greater response to increases in N rate, 361 kg ha^{-1}. The trend within the Nitamin treatments was a gradually decreasing benefit as more N was applied.

Table 3.1. Crawfordsville yield results and N uptake in 2004

		Biomass			**Grain**		
N Material	**N Rate**	**Yield**	**N uptake**		**Yield**	**N uptake**	
		kg ha^{-1}		%	kg ha^{-1}		%
Nitamin	0	8118			9043		
	56	9817	16	29	9638	11	19
	112	7942	7	6	9164	9	8
	168	11854	26	15	10036	14	8
	224	8032	10	5	10487	19	8
Average		**9152**	**15**	**13**	**9674**	**13**	**11**
UAN	0	7958			9524		
	56	7987	5	9	9669	6	10
	112	9603	16	14	9881	9	8
	168	9285	14	9	9798	10	6
	224	13687	65	29	9261	7	3
Average		**9704**	**25**	**22**	**9627**	**8**	**7**
Statistics				p>F			
N Rate		*0.2114*	*0.2788*		*0.1407*	*0.6172*	
N Material		*0.5125*	*0.3725*		*0.7403*	*0.1817*	
*N Rate * N Material*		*0.0571*	*0.0455*		*0.0125*	*0.5106*	

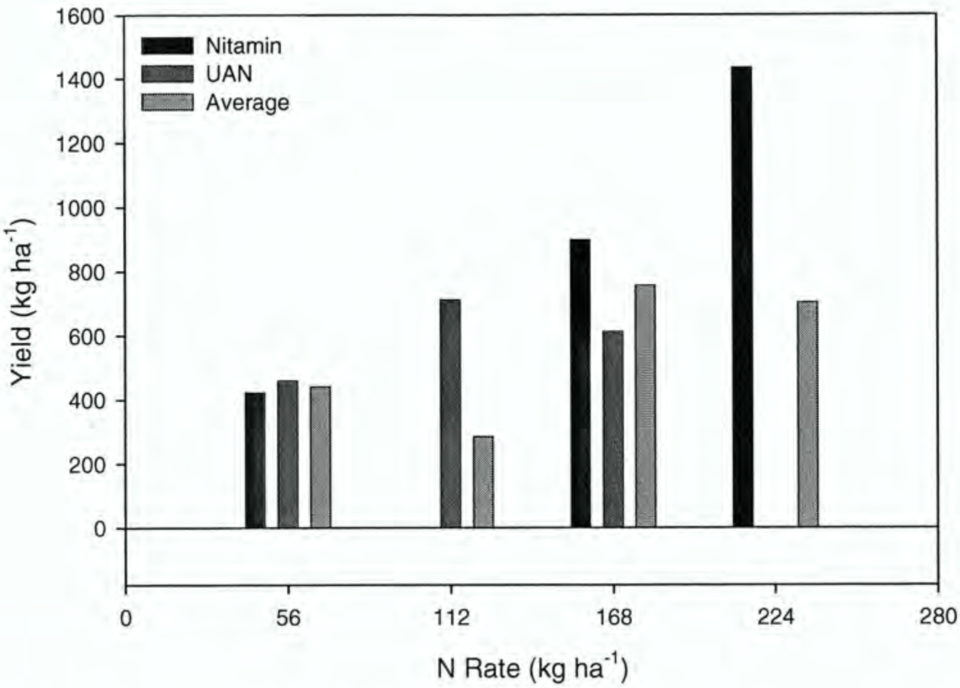

Figure 3.1. Crop yield response to N rate by N material, 2004

The UAN treatments showed no yield advantage for additional fertilizer application (Figure 3.1). The maximum yield was observed at the 112 kg N ha^{-1} treatment, and the control yielded more than the 224 kg N kg $^{-1}$ treatment (Figure 3.2).

Neither N rate nor N material significantly affect N uptake by grain (Table 3.1). Although not significant, there was an advantage for Nitamin in N uptake on a percent and mass basis. The mean uptake of N for Nitamin was 13 kg ha^{-1} (11%) and that for UAN was 8 kg ha^{-1} (7%), and the largest uptake of N was seen in the 224 kg ha^{-1} rate in plots treated with Nitamin (19 kg ha^{-1}) and in the 168 kg ha^{-1} rate in plots treated with UAN (10 kg ha^{-1}) (Table 3.1). The N rates with the largest amounts of N uptake were not necessarily those with the highest grain yields.

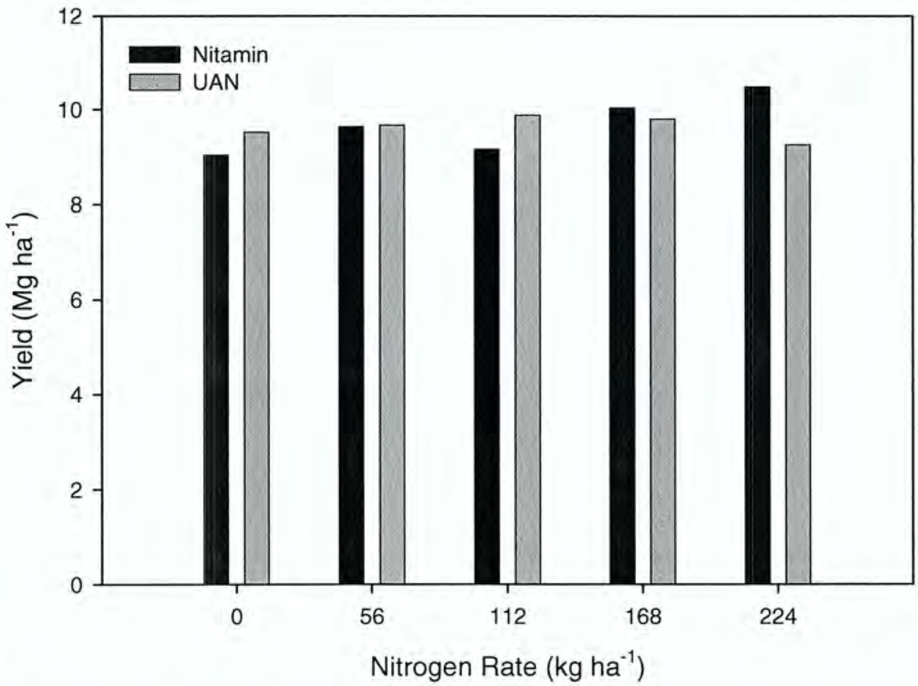

Figure 3.2. Grain yield at Crawfordsville, 2004

Vegetative Biomass Production

Yield of vegetative biomass was not significantly affected by N rate or fertilizer type (Table 3.1). Plots receiving Nitamin had a mean yield of 9,152 kg ha^{-1} with a high of 11,854 kg ha^{-1} (mean of the 168 kg ha^{-1} treatment). The mean yield for plots receiving UAN was 9,704 kg ha^{-1} with a high of 13,687 kg ha^{-1}, in the 224 kg N ha^{-1} treatment (Figure 3.3).

There was a trend for an increase in uptake of N in plots treated with UAN, 25 kg ha^{-1} (22%), over those treated with Nitamin, 15 kg ha^{-1} (13%) (Table 3.1). Although the difference in uptake of N on a percentage and mass basis was not significant ($p>F=0.2788$ and $p>F=0.3725$ respectively). The N rates showing the greatest uptake of N also had the greatest yields of vegetative biomass (15 kg ha^{-1} in the Nitamin 168 kg N ha^{-1} and 29 kg ha^{-1} in the UAN 224 kg N ha^{-1} treatment), this

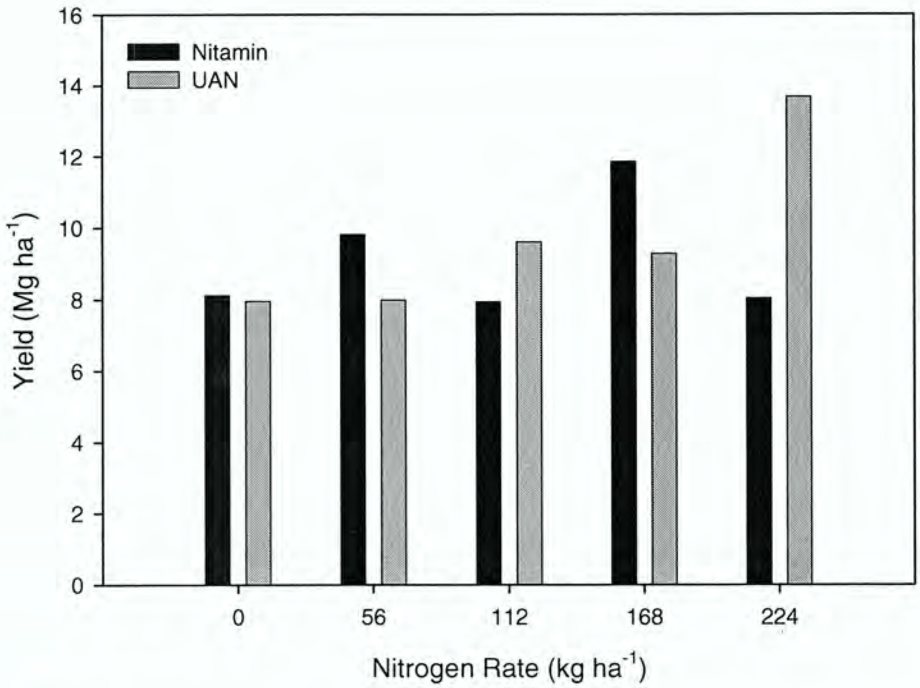

Figure 3.3. Biomass yield at Crawfordsville, 2004

relationship is only present in N uptake on a mass basis. The interaction term N Rate*N Material was significant in N uptake for yield of vegetative biomass (Table 3.1).

Soil Analysis

No factors significantly affected the soil NH_4-N concentrations at the Southeast Farm in 2004 (Table 3.2). There were no consistent trends showing that a single N rate or N material provided a higher concentration of ammonium to the soil at any point in the growing season, although UAN showed a slightly higher concentration in the third sample set (taken at physiological maturity), a mean of 8 kg ha^{-1} in UAN treated plots to 2 kg ha^{-1} in those treated with Nitamin. The only consistent trend is a greater amount of NH_4-N in the soil at the first sampling date (post-emergence).

Only one factor was significant in the analysis of soil NO_3-N. N rate was significant for the first sampling date ($p>F=0.0001$) (Table 3.2). At this time there was also a difference, although not significant, between the fertilizer materials, a mean of 34 kg ha^{-1} for plots treated with UAN and 18 kg ha^{-1} for those treated with Nitamin.

Data Analysis

Data was analyzed for the same factors as described in the previous section, with the use of Statistix 8. However, as there were elements outside the scope of the experimental design, the data was not analyzed for non-representative points.

Table 3.2. Effect of N rate and fertilizer materials on concentrations of soil NH_4-N and NO_3-N at the Southeast Research Farm, 2004

NH_4^+

N Material	N Rate	Sample Set 1	2	3	4-1	4-2
		kg ha^{-1}				
Nitamin	56	10	3	0	3	1
	112	18	4	3	11	0
	168	13	2	1	1	2
	224	17	2	4	5	3
Average		**15**	**3**	**2**	**5**	**2**
UAN	56	12	4	10	13	1
	112	17	4	8	4	1
	168	4	3	7	1	1
	224	21	2	8	2	3
Average		**14**	**3**	**8**	**5**	**2**
Statistics				p>F		
N Rate		*0.5781*	*0.4005*	*0.9803*	*0.6450*	*0.1172*
N Material		*0.8932*	*0.5737*	*0.3050*	*0.7457*	*0.5608*
*N Rate * N Material*		*0.9997*	*0.9811*	*0.7437*	*0.5369*	*0.9790*

NO_3^-

N Material	N Rate	Sample Set 1	2	3	4-1	4-2
		kg ha^{-1}				
Nitamin	56	6	5	2	4	0
	112	15	11	3	13	1
	168	18	5	3	1	0
	224	33	10	3	6	1
Average		**18**	**8**	**3**	**6**	**1**
UAN	56	22	2	2	15	0
	112	35	14	2	4	0
	168	32	7	1	1	1
	224	46	7	1	2	3
Average		**34**	**8**	**2**	**6**	**1**
Statistics				p>F		
N Rate		*0.0001*	*0.1504*	*0.8633*	*0.3970*	*0.3015*
N Material		*0.4995*	*0.5544*	*0.4756*	*0.4064*	*0.9310*
*N Rate * N Material*		*0.5026*	*0.7272*	*0.7447*	*0.4362*	*0.6212*

Discussion

As mentioned in the description of work done at this location there was a fertilizer application outside of the experimental design. Due to the additional fertilizer application there was a limited response to the fertilizer treatments. When data were analyzed for yield only the interaction Material*N Rate was significant. LSD all-pairwise comparisons test showed that only the 168 and 224 kg ha^{-1} N treatments were excluded from the homogeneous group containing the 0 kg ha^{-1} N treatment. In light of the conditions and outcome of this experiment, non-experimental treatment application, and lack of a response to N rate, there are several possible explanations for what caused the results of this field experiment.

It is possible that the 36.3 kg N ha^{-1}, in combination with the N released from soil organic matter (SOM) through mineralization, was sufficient to produce the elevated yields observed at all but the highest N rates. This process is accelerated by strong wetting and drying cycles, which were experienced throughout the 2004 growing season. Upon drying of the soil much of the microbial biomass dies, and when the soil is re-wetted there is a sharp microbial population increase. Due to properties of shrink-swell in soils this re-wetting may expose more N in the soil by breaking soil aggregates, and the recently deceased microbial life serves as an energy source for the new population.

April and May are traditionally very wet months in Iowa. Early season rainfall, 15 cm in May 2004, may have caused loss of large amounts of nitrate-N from the soil. If the urea portion of the UAN had been largely converted to NO_3-N, making it potentially leachable, and conditions were not conducive to release of the slowly soluble portions of the U-F fertilizer there may not have been much of an effect from the applied fertilizer. These conditions could produce very similar yield results between all treatment rates. The higher rates, having a greater initial concentration in the soil, may not have lost as much, on a percentage basis, as the lower treatment rates and therefore may have shown some yield advantage from fertilizer application.

Conditions during the growing season, heat and drought for example, could have been detrimental to plant growth, especially during key times in plant development like pollination. In this case water could have been the primary limiting factor for plant growth, making the availability of nitrate-N an irrelevant factor. It is possible in this situation that soil physical properties, micro catchments of SOM, pore size distribution or other soil properties that would promote water retention, could have been the differentiating factors in determining crop yield instead of the fertilizer treatments.

The different combinations of treatment rates and fertilizer material used may have led to changes in the rate the plants developed physiologically. If these changes were great enough to accelerate or postpone key stages in plant growth there could have been an effect from a coinciding rainfall event with the timing of one of the major yield determining stages of development, such as pollination, there could have been substantial changes in potential and achieved yield that would not necessarily be correlated to increasing rates of applied fertilizer, or fertilizer material.

Finally, greater N rates may have lead to more prolific root production which would allow plots receiving higher rates to have a greater volume of soil from which to extract nutrients and water throughout the growing season.

CHAPTER 4.

CONCLUSIONS

Field trials show a statistically significant advantage for the use of Nitamin as a fertilizer N source, for corn production. However, the clarity of this conclusion is confounded because 2004 data did not show significance. Grain yield was significantly affected by the following factors: rate of N application, year, and location. Yield of vegetative biomass was not affected by either N rate or fertilizer material used, nor was the concentration of N in biomass statistically significant, as affected by fertilizer material used. There were large differences between the years and locations in the study regarding yield of grain and vegetative biomass, soil nitrate-N, as well as total N uptake by all plant tissues.

The inconsistency in the results among years is interpreted as being due to many factors, including climatic conditions involved with availability of N in the soil, the development of the corn plants, and the formulation of the Nitamin fertilizer material. Other factors are possibilities but I could do no more than speculate about them, as they were outside the reach of this study. The U-F fertilizer material used was formulated in separate batches in 2004 and 2005, with differences in reported N content, and therefore it is possible that it had variability great enough to affect the results of the experiment. The different N contents were calibrated specific to that N content, but may have had other unknown variability that cannot be accounted for.

As climatic conditions can affect the release of N from the U-F compounds, through increased microbial activity, it would advantageous to observe the performance of Nitamin in a wide range of temperature regimes and microbial populations.

Conditions for N loss may have existed during the two years involved in this study. It would be of great benefit to be able to take more regular soil samples in order to approximate a release curve as described under the specific temperature and moisture conditions, in combination with the hydrology of different soil types that exist in a given season at a given location. This information could allow a more precise prediction for the amount of N fertilization that will be available to the crop at different times in the plants life cycle. A more accurate calibration of plant needs, over time, and N availability could then be created and implemented to achieve more efficient nutrient management, concerning N fertilization.

More research is needed to determine how Nitamin fertilizer will function under different climatic conditions, both in the particular formulation tested here and different formulations and delivery methods, impregnated into expanded vermiculite and as a coating on sand for example. Although the two years of this study showed a significant impact on yield production with the use of Nitamin, until there is a better understanding of how this type of fertilizer will behave under a wide variety of conditions there cannot be an assurance that it will out-perform traditional forms of N fertilizers, although positive environmental impacts may be realized prior to economic benefits.

Concerning the research conducted at Crawfordsville in 2004 with only one year of data, conclusions will not be made. However, there were trends present worth noting. With the lack of response in yield until high rates of N application, 168 and 224 kg ha^{-1}, this study would suggest more work be done in the area of yield responses to decreased N rates in different conditions and cultural practices.

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